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PAPERS

2

READ BEFORE THE

ENGINEERING SOCIETY

OF THE

SCHOOL OF PRACTICAL SCIENCE

TORONTO

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This Society is not responsible as a whole for any statements or opinions expressed by any of its members or others in the following pages.

PREFACE.

The present number contains papers read before the Engineering Society of the School of Practical Science during the session 1894-95.

The Society was organized in the year 1885 by the students then in the School, and has gradually grown since that time. Every alternate Wednesday afternoon during the session is set apart from the regular time of the course for the meetings of the Society, so that students may thus take advantage of them without sacrificing any of their time.

This number shows a marked increase, both in size and in the general character of the papers contained in it, over all previous ones, which is, no doubt, due to the larger number of graduates, but more particularly to the encouragement offered by the Faculty of the School to students writing papers, as a good proportion of our undergraduates have contributed.

A valuable addition is the discussion which has been printed at the end of papers. This discussion has been obtained in most cases by having printed, some weeks before the presentation of a paper, a large number of copies of same, which have been distributed amongst the members and others interested in the subject dealt with. The present number shows that this method of obtaining discussion and thus greatly increasing the value of papers is very satisfactory.

In sending papers to the Society writers should use only one side of the paper, and should leave a good margin on the left-hand side of each sheet.

1,500 copies constitute the present edition, and these will be widely distributed amongst the members and others interested.

April, 1895.

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ENGINEERING SOCIETY

OF

The School of Practical Science

TORONTO

PRESIDENT'S ADDRESS

GENTLEMEN,—It is impossible for me to find words to fully express my thanks and appreciation of the honor you have conferred upon me in electing me president of your Society, for, by so doing, you have made me the recipient of the highest office to which an undergraduate of our school is eligible.

And, if it were not for the support you have given me in the very able committee you have seen fit to elect, I would be unable to undertake, with any degree of assurance, the responsibilities connected with the position, especially as I am expected to fill the place just vacated by one of the best presidents, as well as the most able chairman, the Society has as yet had at its head.

With the assistance of the committee, however, I will do my utmost to give the Society no cause to regret having elected me to fill the chair for the present year.

I am pleased to see that we have with us to-day a number of new members, and it gives me great pleasure, on behalf of the Society, to welcome them to our meetings.

I must also congratulate these gentlemen of the first year upon their choice of a profession, for, undoubtedly, we have before us a greater field for our labors than has any other professional man.

It will not be necessary for me to dwell upon the object of our Society, as copies of the constitution, containing this and other information relating thereto, can be had from the librarian.

Thanks to the untiring efforts of the last committee, our Society is in a first-class financial condition. In addition to this, the roll of last year shows a greater number of members, and greater average attendance, than in any previous year. These facts, I must say, gentlemen, reflect great credit upon the committee of 1893-4.

We cannot expect to be able to make a better showing, financially, for the current year, but I sincerely hope that our average attendance will show another increase.

The time for our meetings, as most of you are aware, has been granted by the council from our regular school hours, and the attendance at these meetings is considered as part of our college course. Apart from this, however, as coming engineers, we should not throw away a chance of hearing valuable papers read and participating in the discussion thereon.

Although the paper before the Society may not be in our own special line of engineering, that is all the more reason we should want to hear it; for, undoubtedly, the broader we are in our studies, the better will be our ability to become thorough as specialists in any of its branches.

Again, as every engineer has, very often in his career, to speak before an assembly of some kind, we should not lose an opportunity to gain confidence in speaking, and also of being able to express our views clearly.

For this purpose, discussions are entered into after every paper is read, thus giving each member a chance to ask questions and state his ideas on the subject under discussion.

This is a golden opportunity, gentlemen, and one that should be grasped by every one of us; for, remember, we are here among friends but three short years, and after that time will have to speak before strangers, who will not (if you will pardon my use of a slang expression) "call us down" when we make a mistake, but will mentally, or perhaps through the press, note the fact. I therefore repeat what I have already said—do not miss a chance to become a speaker.

To make the discussion of papers more general, and also to make our yearly pamphlet more interesting and complete, it was decided at a general meeting, held towards the end of last year, to adopt the plan of having about 150 proof sheets of each paper struck off and distributed among the engineers and specialists on the subject throughout the country, asking them to discuss the paper in writing and send it in to the Society.

The paper and discussions thereon will then be read at the next meeting of the Society, and afterwards printed for the pamphlet.

This plan of securing discussions is, at the present time, working very satisfactorily in a number of American societies, the discussions, in many instances, being as valuable as the papers themselves.

The work of the editor and publishing committee will, under this new system, be less arduous, as it will spread out over the whole year, and will not, as heretofore, be limited to a few weeks. It will also enable the committee to have each year's pamphlet ready for distribution at the end of that year, instead of, as at present, the middle of the next.

I fully believe, therefore, that in the adoption of the preceding scheme, which is due to Mr. C. H. C. Wright, the Society has taken a decided step in the proper direction, and I am looking forward with interest to see the idea carried through successfully this year.

At the first meeting of the present committee last spring, the question of obtaining papers from the undergraduates was brought up, and, after carefully considering the subject from all points, it was decided to petition the council to grant a bonus in the way of marks for these papers. This was done, and as there was not going to be another regular meeting of the council before the examinations Professor Galbraith very kindly called a special meeting of its members to consider our request, the result being that your present committee is authorized to award marks to every student writing and reading a paper before the Society. These marks are not to exceed 100, and are to be awarded according to the value of the paper. All marks over 50 will be considered by the council in granting honors.

Some of you will, no doubt, say that as you do not intend to try for honors, it is no use your thinking of writing on any engineering subject. This, in my opinion, is very poor argument, for you must remember that we are here to become engineers, and should avail ourselves of every opportunity to forward our own interests, as well as those of the Society; and the writing of a paper would be of very great assistance to each one of us. I see, therefore, no reason why we should not have a paper from every second and third year man in our school, as well as a few from the first year; for by so doing we will not only benefit ourselves, but will show the faculty that we fully appreciate the interest that they take in us as a Society.

The library, which is under the control of the Society, is being increased every year, new books on scientific subjects being continually added to it by the faculty, as well as by ourselves. These books are carefully selected, and are the best that can be procured on mining, civil, mechanical, and electrical, as well as architectural work. All members have not only the use of the library, but also the privilege of borrowing, for a certain number of days, any book contained therein.

I hope you will all take an individual interest in any business that may be brought up throughout the year; for, remember, that every motion adopted or rejected will have its effect in forwarding or retarding the advancement of the Society. You should therefore give every matter of business your careful consideration before voting upon it, and by no means hurry a motion through without carefully discussing its effect on the Society.

Finally, I must ask you to watch carefully the work of the committee you have appointed to transact the business of the Society. Give them your instructions and see that they are carried out, for by so doing you will show them that you are interested in their doings, and consequently in the welfare of the Society.

Before sitting down, I wish to refer to the recent appointments made in our school, and in the first place to that of Mr. J. A. Duff, B.A., to the position of lecturer in applied mechanics.

Mr. Duff, as you are all aware, has been intimately connected with our Society for a number of years, and has, perhaps, done more to further its interests than has any other individual member.

The Society has been further honored in that three of its most prominent members have been granted fellowships. I refer to Mr. A. T. Laing, Fellow in Civil Engineering; Mr. K. W. Angus, Fellow in Electrical Engineering; Mr. J. Keele, Fellow in Architecture.

It gives me great pleasure, on behalf of the Society, to congratulate these gentlemen and wish them every success.

A. E. BLACKWOOD.

October, 1894.

GRADING

W. L. Innes, O.L.S., C.E.

The "grading" referred to is for railroad purposes, but the remarks will hold true, to a certain extent, for all kinds of grading. For the sake of economy, the banks are usually formed of the material excavated from the cuttings, side ditches, etc. In some cases, however, it is cheaper to "spoil," or waste, the material, and make up the embankment from "borrow pits." For instance, suppose the cuts and fills for some particular locality of the line do not balance—that is, suppose it would be necessary to haul the excavated material a very long distance to make up a fill—it would probably be cheaper, under these circumstances, to dump it anywhere convenient to the cut, and make the fill from material near at hand to the proposed embankment, as the contractor is usually allowed a certain amount per yard for additional haul over a specified distance. The cuts and fills, under ordinary circumstances, should about balance, care, however, being taken to add about 10 per cent. to the calculated number of cubic yards of filling, as it would take, ordinarily, about $1\frac{1}{10}$ cubic yards of earth, as found in the natural bed, to measure 1 cubic yard in an embankment properly made up.

The contractor is generally paid so much per cubic yard for excavating, and, unless in special cases (an instance of which has already been referred to), he is required to deposit it in an embankment; so that the work is only paid for as either an embankment or an excavation, and not as both. In making up quantities this should be remembered, and the sum of the cuts and fills should not be taken as the total, but either of them, if they are about balanced, the greater always.

The quantities should always (except in special cases) be measured in excavations, because of the uncertainty of the exact allowance that should be made for shrinkage, if measured in embankment. It varies a great deal with different kinds of material, and even considerably with the same kind, depending upon how it has been compacted. Trautwine's Engineers' Pocketbook gives it to be as below on the average:—Gravel or sand, 8 per cent.; clay, 10 per cent.; loam, 12 per cent.; loose vegetable surface soil, 15 per cent.; puddled clay, 25 per cent.; and this is confirmed by

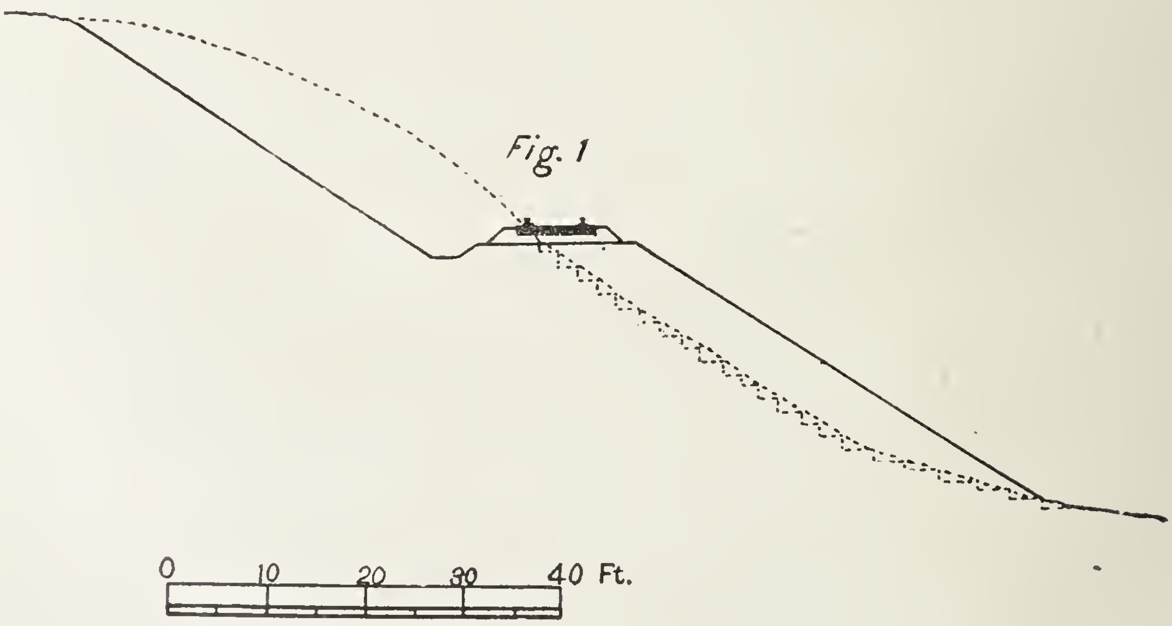
Mr. Q. A. Gilmore, in his book on "Roads, Streets, and Pavements," familiar to you all.

The materials best adapted for embankments are those that will form themselves into a firm, compact, and permanent mound in the shortest time after being deposited in place. Any kind of earth that is free from water, that will be but little affected by water, and that will not retain it long—that is, that will allow of the water that falls on it being drained away quickly—will answer for this purpose very well. Some earths, notably certain clays, seem to retain about them a large amount of water, and when exposed in slopes of either embankments or cuttings, especially the latter, will be washed down more or less by every rain, and every time a frost comes out. Thus new surfaces are being continually exposed, and in slopes of this kind of material it is a very long time before they will be covered by a growth of grass or other vegetable matter, unless specially treated by one of the methods to be described later. The greatest difficulty is always experienced in cuttings, as embankments always afford better drainage of the materials. Some other materials of a sandy appearance, and of such a nature that, when cut, act more like a liquid than an earth, cannot be depended upon to form safe embankments, even after having the slope sodded, unless they are of a much less inclination than usual, say, two or three horizontal to one vertical. Clean gravel is typical of a material neither retaining nor so injuriously affected by water.

An embankment should never be made up of frozen materials, as it is almost certain to slide when the frost comes out.

If the embankment is to be formed on a sidehill, and there is any chance of it sliding, the surface of the original ground should be broken by deep ploughing, or be cut into strips (Fig. 1). On sidehill ground,

Fig. 1



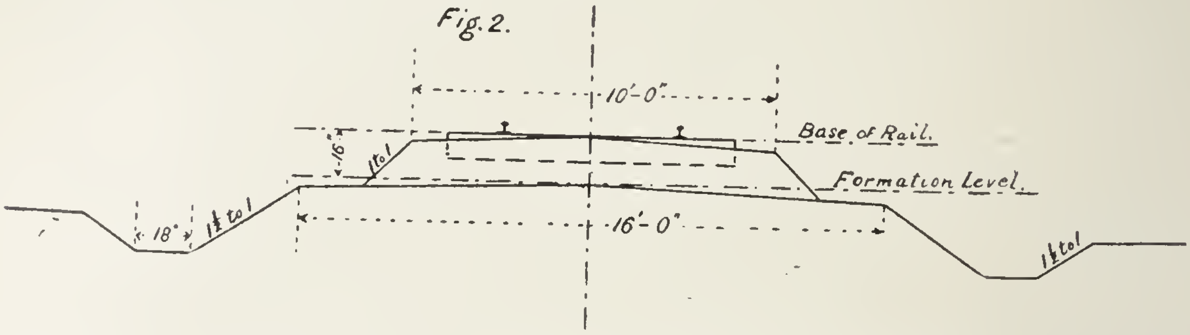
when it is wet and spongy, or likely to be affected by water, it should be thoroughly underdrained, so that no water will lodge between the old and new banks. This may be done by means of trenches cut longitudinally and transversely to a depth of about three or four feet, or to the source of the springs, with open joint tiles placed in the bottom, and the trench filled with a material that will allow the water to drain away quickly, or by any form of convenient blind drain.

When a new line is being built, it is frequently, for various reasons, more economical in first cost, besides being much quicker, to build a trestle over a ravine, then an embankment. At the end of the life of the trestle, it may be desired to make a permanent embankment, after first providing suitable openings for any waterways or undercrossings that may pass under the bridge. Under these circumstances, the material would be hauled to the top of the bridge, on either flat or dump cars, and unloaded there. In this way the bulk of the material would fall about the centre of the dump, and unless spread out would form a very unstable embankment, as the layers would be approximately parallel to the finished slope. The sides of embankments should always be kept a little higher than the centre, in order to retain the rainfall, and consequently hasten the consolidation of the whole mass.

The slopes should be less than that which they will naturally assume, in order to give them greater stability. Usually, 1½ horizontal to 1 vertical is found to answer very well for earth. Sometimes, however, it is necessary, owing to the nature of the earth, to decrease this to 2 or 3 horizontal to 1 vertical. It will be noticed that the inclination at the upper end of an old slope is always steeper than at the lower end. Something as shown in Fig. 7. This being the case, it would be worth while making them conform more to this shape than to the rigid 1½ to 1 slope. If done in the first place it will save trouble from this source later, as it is almost certain to assume this form eventually, and the extra material required at the foot of the slope must be made up from that sliding down from the top, thus narrowing the top of the embankment and allowing part of the ballast to be lost, unless prevented in the first place as suggested. The width of the embankment at the top or formation level (Fig. 2) should be enough to prevent the ballast from sliding down the slopes and being lost. It should not be less than 16 feet for a single track.

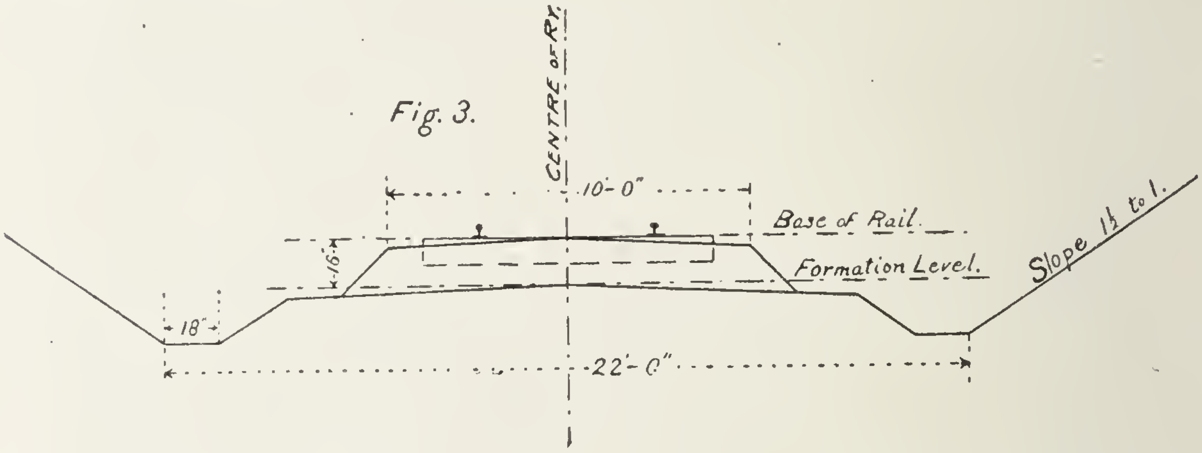
In finishing up the top of an embankment, it should be made a little higher in the centre than at the sides, so as to hasten the escape of the water that falls on the roadbed and settles through the ballast (Fig. 2). It is indeed a fortunate thing for all concerned in the welfare of the railroad, but particularly so for those who have to do with the keeping up of the roadbed, if all the cuttings come in dry, porous material ; but it is equally unfortunate if, on the other hand, they are in wet, spongy material, easily affected by water and containing springs.

Fig. 2.



For a single track the cutting should not be less than 22 feet wide at the bottom (Fig. 3).

Fig. 3.



The slopes should be about the same for a cutting as for an embankment, that is, ordinarily, 1½ to 1, and the same remarks regarding lighter slopes and giving them a concave shape will apply here with equal force as in the case of an embankment, even though it is usually the aim of the contractor to give them a convex shape in cuttings to save work.

In any case, side ditches should be provided, and with as good a fall as possible, so as to carry away the water that collects in them quickly, and not allow it to soak into the substratum under the ballast, or, if the substratum is wet and spongy, to provide it with as good drainage as the circumstances of the case will permit. If the substratum remains soft and wet, it will allow the ballast to be sunk down into the mud (for a soft and wet substratum will amount to, in time, practically nothing more) by the action of passing trains, and the mud to work up about the ballast and cross-ties, making a soft, springy roadbed which can neither be kept in line nor in surface, and which, if proper drainage is not procured, will cause endless trouble and expense. For the reasons just mentioned, besides others, long level crossings are very objectionable.

Drainage about the roadbed is very important, but particularly so in cuts. Every time a train passes over a soft, wet roadbed, similar to the kind just mentioned, it will shove the ties further down into the mixture of mud and ballast, until finally they will be completely buried and the place becomes impassable, if not remedied. Two great mistakes are sometimes committed in making cuts: first, the cuts are not wide enough at the bottom to allow of good side ditches; the second, the slopes are made too steep. These two points should be carefully looked into at each cut, or, at the least, for cuts in all the different kinds of material.

If the material of which the slope is composed is wet and contains springs, it is not only very likely to slide in cut matter, but even more so when the frost comes out. It is very difficult sometimes to know what is best to be done under these circumstances, and no rule can be laid down to cover all cases, as each must be treated somewhat specially. Some advocate sodding the slopes, but this will probably prove of no avail, unless at the same time stakes about 2 or 3 feet long are driven into the slope at fairly close intervals; then it is claimed that this will effectually stop sliding in cuts. Instead of sodding, a thin layer of loam may be spread over the surface of the slope, and then seeded down with grass seed; of course it will be just as necessary now, if not more so, to use stakes as before. Anything of this kind greatly improves the appearance of the cuts, besides probably making a permanent improvement; but, as a rule, it is a difficult matter to get the management of a railroad to expend money in this way, although they apparently have no objection to sending out a train with a large gang of men each spring and fall to clean out cuts of the material that has slid down during the half year from the slopes, and this is only a temporary relief from the difficulty. It must be remembered, however, that unless the slopes are made up approximately in accordance with the shape which they will naturally assume in time, and as indicated in Fig. 7, and it is very doubtful if sodding or anything else will prevent sliding in cuts of certain wet materials, when acted upon by heavy rains or frosts, unless the slopes are very slight, which, generally speaking, is not the case.

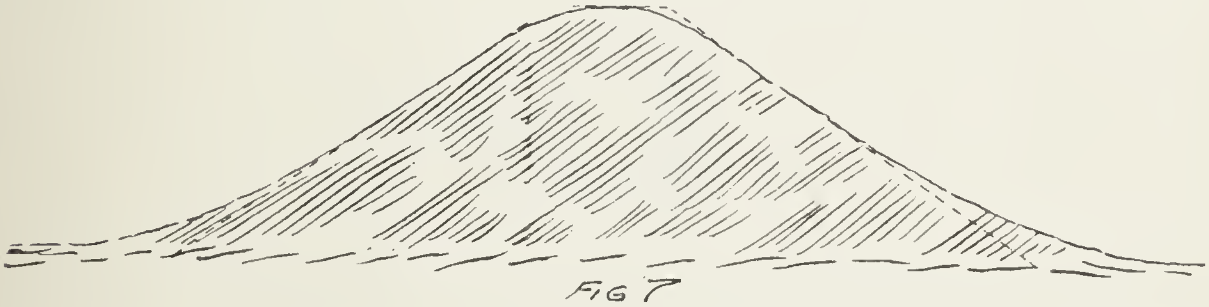
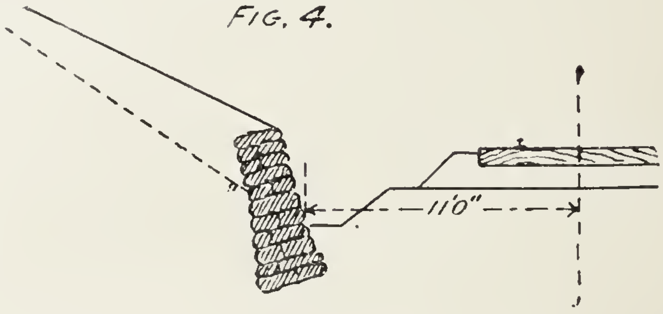


FIG 7

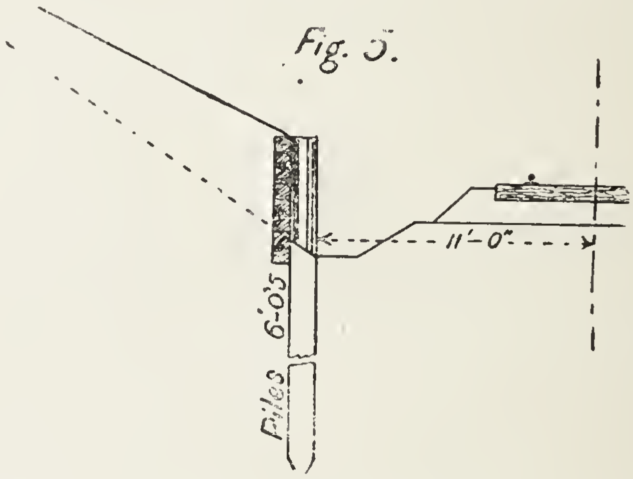
A variety of frost works have been designed and used for retaining the foot of slopes in cuts, only a few of which will be mentioned. Dry stone retaining wall, or "rip rap" (Fig 4). The stones should be large,

FIG. 4.



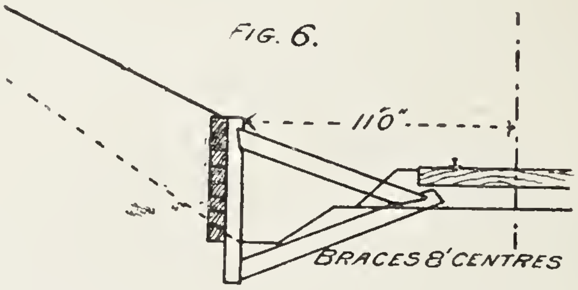
and the spaces between the stones should be sufficient to allow the water to escape into the side ditches and thus carried away. If cement is used, drip holes should be provided; otherwise water will collect behind the wall, and, when it freezes, break the wall. Piles driven about 6 to 8 feet centres, and backed up with old bridge timber (Fig. 5), make a good retaining

Fig. 5.



wall for the foot of slopes in cuts, provided that the wall does not exceed about 5 feet in height. Perhaps the best plan for this purpose is shown in Fig. 6. It has proved to be very effectual in answering the purpose

FIG. 6.

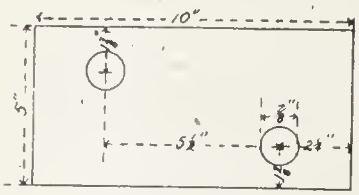


for which it was designed. It is built entirely of old bridge timber, and, the construction being simple, it is not costly.

Ties settling into the mud during wet weather, caused, indirectly, by poor drainage in cuts, or a substratum of water-retaining material, is only part of the trouble. When the cold weather sets in, "heaving" of the track will commence, and continue until the frost has reached its maximum penetration into the ground. In some cases the track will be shoved up as much as 6 and even 8 inches, and, in an extraordinary case, it has heaved as much as 14 inches; but the ordinary maximum is 4 to 5 inches. The writer, in speaking with an experienced section foreman, some time ago, on this subject, was informed that he had, on one occasion, dug down at the ends of the ties when the track was badly heaved. After passing through the ballast, which, of course, was frozen, he found that there was intermingled layers of sand, ice, and air spaces, varying in thickness from about ½ inch to about 1½ inches. The substratum in this case was quicksand. The foreman thought that water was the cause of all bad heaving—in fact, of all heaving—and stated that, in a number of cases of bad heaving investigated by him, he found that, invariably, there was always considerable water present in the substratum. A certain amount of heaving is likely to take place anywhere along the line, but no really bad heaving occurs except in cut places. The greatest trouble is generally experienced at the ends of cuts. Heaving is seldom the same for any considerable distance along the line, and this is what causes the trouble. Sometimes one rail may be pushed up and the opposite one remain as it is, or one end of the same rail will be heaved up, while the other end remains unmoved. The amount of heaving seems to depend directly upon the amount of water contained in the ballast and substratum within the range of frost. The more water, the more heaving. This is explained, no doubt, by the well-known property of water—expanding when transformed into ice; each additional penetration of the frost adding its quota to the heave. This also explains, or seems to explain, the appearance of air spaces and layers of ice and sand, as found in a frozen roadbed mentioned above. The frosts might reach deeper in certain spots than others, thus including more water and causing more heaving, leaving spaces under the other spots when the frost did not reach down so far. These spaces might then be filled, or only partly filled, with water, which, when reached by the frost, would form an air space and a layer of ice, or an air space, a layer of ice, and a layer of sand, according to the increase of the depth of the frost, etc. These would, in their turn, probably be heaved up, and a similar process continue until the frost had reached its maximum penetration. A remarkable case of an air space being found under a track has been related to the writer by a roadmaster of wide experience. The space in this case, to use his own words, "was large enough to let a rabbit run under the roadbed." The heave in this case was extraordinary, being about 14 inches. In order to keep the two rails level, or at the proper elevation, if on a curve, or to take the ups and downs out of the track, since the ties are frozen in and cannot be either raised or lowered, it becomes necessary to use shims. Adzing the ties should never be allowed. Shims are simply pieces of hard, tough wood, varying in size to suit the weight of rail, with two holes, $\frac{7}{8}$-inch diameter, bored through them for the spikes to pass down, and so placed that the spikes will fit close to the flange of the rail. Figs. 8, 9, and 10 are plans of shims for the different weights of rails; and Figs. 11 and 12 show the method of using them.

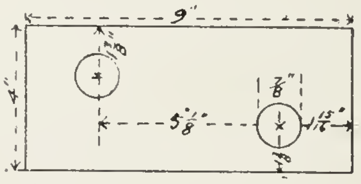
SCALE, ¼ SIZE.

FIG 8.



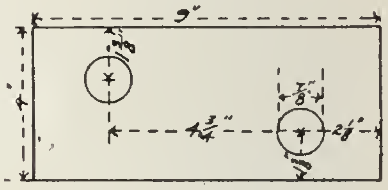
SHIM FOR 72LB. RAIL

FIG. 9.



SIUM FOR 60LB. RAIL

FIG. 10.



SHIM FOR 56LB. RAIL

Fig. 11

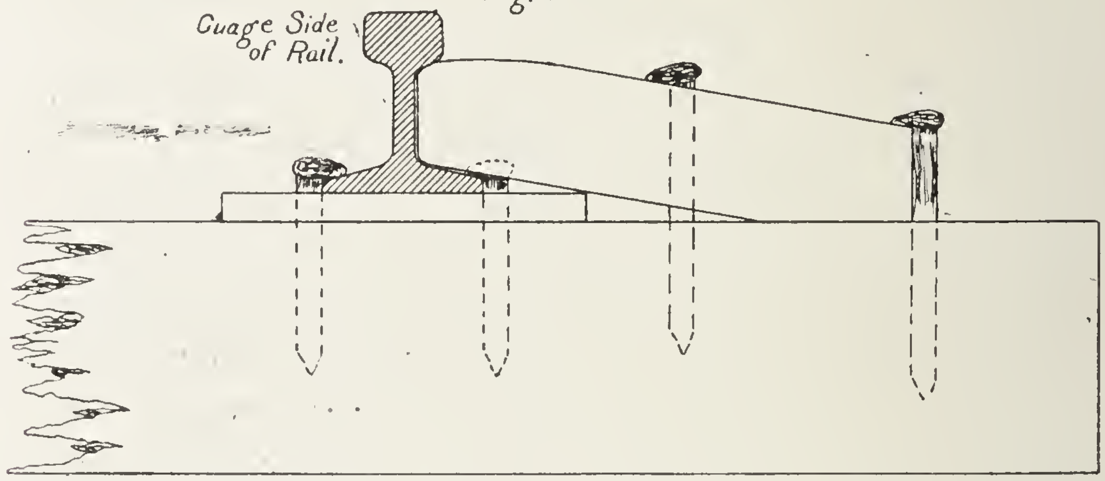
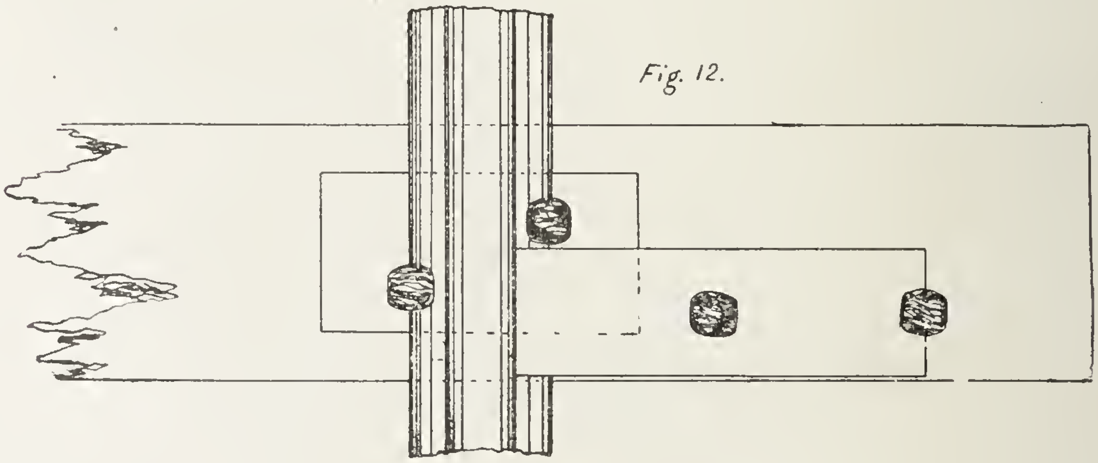


Fig. 12.



Shims are generally supplied the sectionmen machine-made, of various thicknesses, varying from $\frac{1}{4}$-inch up to 3 or 4 inches. For anything less than $\frac{1}{4}$-inch, the foreman should have a block of tough hardwood on his hand car, from which he may chip off the desired thickness of shim. When thick shims are used, the ordinary track spike, which is about 6 inches long, is too short to hold well, and spikes 8 and 10 inches long, but otherwise of the same dimensions as the ordinary, are used. At first the upheaval is very slight, but becomes more marked as the weather grows colder and continues till the dead of winter. However, this is not always the case, as frequently the track will heave once and remain undisturbed until the frost goes out. When the upheaving continues, it is necessary to commence with thin shims, and gradually replace them with thicker ones as the change proceeds. Similarly, when the frost is going out, it is necessary to continually change them and reduce the thickness until the last shim is out.

It will be noticed that drainage in cuttings, soft springy roadbeds, heaving, shimming, etc., have been considered under the head of grading. This was done for the purpose of bringing out the intimate relationship existing between them. Very often, at the time grading is going on, by using proper precautions, a great deal of soft roadbed and bad heaving, and consequently the dangers and expenses appertaining thereto, may be avoided

The cost of excavation, of course, will depend upon the nature of the materials to be excavated, the locality, the price of labor, and also upon the circumstances generally; so that no one price can be given to cover every case, but the price per cubic yard for earth usually ranges in the neighborhood of 20 cents.

Trautwine gives some very useful tables for cost of excavation on page 742 of his Pocketbook.

Peterborough, Oct. 13th, 1894.

DISCUSSION.

Mr. C. H. Mitchell. —Mr. Innes' paper supplies a valuable part to our preceding papers on railroad work. We have previously had considerable information on earthworks and track-laying, but this paper very aptly closes the gap between them. Mr. Innes has presented us with a considerable amount of valuable concise general information on the question of grading, but that which I consider the most valuable is his clear and complete treatment of the frost question, and in view of the climatic conditions in this country it is most important to the engineer. In view of the fact that Mr. Innes' paper is the outcome, for the most part, of his personal experience in railroading, his paper is doubly valuable.

In reference to the drainage of cuttings, where the soil is springy, the most effectual way to prevent trouble is to strike at the root of it and gather the water into drains of some kind before it gets to the roadbed, or surface of the cut. If the springs are near the surface of the original ground, they can be tapped by wells situated back of the crown of the slope, and filled with loose stone. An ordinary drain leading from the bottoms of these wells would carry the accumulated water to any desired place. If the water comes out on the slope of the cut or near the roadbed, blind intercepting drains of loose stone, not necessarily deep, and running diagonally down the slope, would gather the water and convey it down the slope to the side ditches, which, if sufficiently deep, would protect the roadbed.

MR. JAMES MACDOUGALL.—I am glad to see a paper on grading having a place in the proceedings of our Society, as it, and other forms of earthwork, hold such an important place in the various matters that an engineer is likely to have to deal with; in fact, it may almost be said to form an important part of every engineering work. As a friendly criticism, I might say that the paper, in my opinion, lacks definiteness in some particulars.

My experience has been that the young engineer sometimes lacks a knowledge of the customary methods of calculation. One case in my own experience was that of extra haul. The specifications generally contain something similar to this: "Extra haul will only be paid for when it exceeds one thousand feet, and then at the rate of one cent per cubic yard per additional one hundred feet up to two thousand five hundred feet total haul."

The reason for limiting total haul to two thousand five hundred feet is evident, as then the extra haul would amount to fifteen cents per cubic yard, and when that price is reached it would be about as cheap to borrow nearer at hand if the excavation price is under twenty cents, as is frequently the case. Methods of calculating extra haul are numerous. When one is in a hurry, and complicated methods are forgotten, it is perhaps as well to take the profile and work each way from grade by station lengths, or shorter if the notes permit, until the haul reaches the beginning of extra haul, allowance being made for shrinkage. Then you have a certain fill between two sections and a certain cut between two sections. If they balance, the extra haul is simply the half length of the prism in cut added to the half length of prism in fill. If they do not balance, the balance either comes from the next prism in cut to fill up same prism in fill, or comes from same prism in cut to next prism in fill. This method is pursued until either cut or fill is gone through. Making thus a table, with the various quantities and corresponding distances of extra haul, multiplying out, adding, dividing by 100, and multiplying by the price per 100 feet, the total value of extra haul is arrived at. This, of course, is an approximation, the assumption being that the centre of gravity of each prism is at the centre of length, which is seldom true in fact.

I have tested Trautwine's percentages as to shrinkages in fills in some instances, notably in gravel, and have found them to check out closely when applied to the cuts from which the material was taken. The young engineer should verify these and similar results of experience as often as he possibly can.

As regards the material of which embankments should be made, I may say that an engineer seldom has much choice. I have made embankments which we afterwards had to cover with clay to prevent their being burnt up. These were made by piling up black muck in long swamps where no solid material was obtainable, until the track was got through. When it dried, it was quite inflammable. I have also used large quantities of frozen material, as the exigencies of railway building sometimes do not allow for weather. These matters, however, are easily rectified after the track is once laid, when large cuts and borrow pits can be cheaply run out. Mr. Innes' remarks as to depositing the earth in layers are to the point, and the importance of doing embankments in this way is too much underrated in practice.

Mr. Innes has not quite brought out the idea of the agreement of a twenty-two-foot cutting with a sixteen-foot embankment. If you will take a twenty-two foot cutting and allow eighteen inches as the width of the table drains at bottom and six inches for depth, and give their sides the usual slope of $1\frac{1}{2}$ to 1, you will find you have a small middle embankment left which is exactly sixteen feet wide, and is, therefore, continuous with the embankments at either end of the cut. This, I assure you, looks even better on the ground than it does on paper. The fact is, cuts should be taken out to widths suitable for leaving this width of grade, and providing for any size of table drains that the nature of the ground may require.

Blue clay in cuttings should not be left exposed if top soil of any kind is handy. In damp weather the clay cracks vertically and falls forward, filling up the table drains. I had a large cut which was taken out by steam shovel. The cuts, of course, were nearly vertical, and were taken out to about midway between the bottom and top widths. I found that there was scarcely any more trouble after the top soil had fallen down and covered up the hard blue clay. Previous to that, even a misty atmosphere would start the cracking of the clay.

One of the frost works described by Mr. Innes—shown in Fig. 6—could, I think, be improved on by laying in a horizontal sill of rough timber just below the level of the table drain and extending to the centre of the track. On this erect your vertical post with mortice and tenon at the foot, and put in the brace as before, but with the foot below the ballast on the top of the sill. I have seen these remain in place until they have rotted out.

In wet sand cuts, a box drain with sides of square timber, resting on cross sills every six feet, floored with plank, and open at top, except for cross ties, is frequently very efficient.

MR. A. T. LAING.—Is it not preferable to avoid the use of wooden structures for retaining walls, and would it not be advisable to dispense with walls altogether, if possible, by widening the cut, even though this involved the expense of procuring more land?

MR. JAMES MACDOUGALL.—Wooden structures are objectionable, of course, but in the case of new construction it answers the purpose for the time being, and facilitates the progress of the work. At the end of ten or twelve years it will need repairing, at which time it may be replaced by stone. With reference to widening the cut, this in many cases is the more permanent way of overcoming the difficulty, but in some kinds of soil no reasonable width of cutting will prevent sloughing; also in long, deep cuts it would be found very expensive to remove the material. In such cases it would be preferable to construct retaining walls.

MR. A. T. LAING.—In the case of shimming, I think it would be better to use shims without holes. These may be placed diagonally underneath the rail between the spikes, thus facilitating the labor both of placing and removing the shims, and it will be found less injurious to the tie, as the spikes need only be partially drawn.

THE MAINTENANCE OF ENGLISH ROADS

By Sidney M. Johnson, Grad. S.P.S., Stud. Can. Soc. C.E.

In this short paper I do not intend to touch upon the construction of new roads, nor will it be necessary to point out to you the advantages of well-maintained roads, but my object is to bring before you as concisely as possible the system by which the English roads are maintained under County Councils, and also the cost of this method.

But before entering upon the subject of maintenance, I must give you some of the history of these roads.

The earliest roads of England about which anything certain is known are those laid down by the Romans during the time they occupied the country. These are characterized by their straightness from point to point, and by the solidity of their foundations, which in many cases consisted of carefully constructed pavements, sometimes cement being used, and upon these the roads were constructed. Many of these roads still exist, or form the foundations of the present roads.

The roads laid out after the Roman occupation are by no means characterized by their straightness, but were laid out without regard to system, attention being paid only to the requirements of the traffic, and as to where the best road could be built at the least expense. Thus we have the road following the brow of a hill, a valley, the course of a stream, or else constructed to suit the convenience of the owner of the land, and these causes produce the pretty winding roads and lanes which add so much to the beauty of the country, as contrasted with the regular concessions and sidelines of our own.

This method has advantages more important than that of picturesqueness, for by deviating the road, instead of cutting through hills, it may be kept upon nearly the same level, and a much better bed thus selected. Another advantage is in the matter of bridges. In parts of England there are a great many deep winding sluggish streams and rivers, and the roads have been laid out so as to have as few bridges over these as the convenince of the traffic would allow, thereby greatly lowering the cost of maintenance.

The system of maintenance, until the latter part of last century, was very similar to that in vogue in Canada at present. The law then required each parish to repair its own roads, which they did by statute labor.

Early in this century turnpike trusts were formed, but these were conducive of very little improvement.

In the year 1819, and those following, greater interest was aroused by the keen competition for favor between the rival systems advocated by McAdam and Telford.

These men both, for the first time, advocated the thorough drainage of the foundation and the breaking of the material to a certain gauge, but differed in that Telford advocated a pavement upon which to build the road, while McAdam maintained that this was unnecessary.

In 1835 the "General Highways Act" was passed, by which highway rates were substituted for the statute labor, and paid surveyors were authorized for parishes or highway districts. This Act, with slight modifications, continued in force until the County Councils were constituted by Act of Parliament in 1889, when the present system was called into use.

Under the present system the roads are divided into two classes, viz., County and Parish roads, the former including all the old turnpike roads and many of the other main roads, whilst all other roads come under the latter heading, and the parish in which they are situated is responsible for their maintenance.

The details of the system adopted vary slightly in different counties under the County Councils, depending greatly upon the engineer, but are very similar upon all major points.

The outline of the chain of responsibility or system of maintenance which I am going to detail is that followed in the County of Norfolk, one of the large counties on the east coast, and which possesses very good roads.

Here, as in other counties, the county roads are placed by the council under the supervision of an engineer, who is known as the County Surveyor.

If the parish authorities think that the traffic upon any of the roads under their supervision is more than local, or that it should be classed as a main road and the county made responsible, they must apply to the council for relief, at the same time setting forth their claim. The county surveyor is then instructed to examine into the case and report. In case it should, in his estimation, be classed as a main road, the parish must first bring it into as efficient a state as the county roads, and they may be relieved of its care, it then becoming a county road.

The county surveyor appoints his own assistants, who are known as Overseers or Local Surveyors. These men should have previous experience, as they have, on an average, the supervision of one hundred miles of road, devoting their whole time to the care of their section. Their first duty is to inspect their section, and this they must do personally at least once a fortnight, and send a written report to the county surveyor.

The engineer also convenes a meeting of these local surveyors once a month, when their successes and failures are reported and discussed, and thus they severally profit by the experience of each one.

In the county I have mentioned there are, in round numbers, twelve hundred miles of main or county roads under the charge of twelve local surveyors, each having about one hundred miles in his district.

The local surveyor has under him a laborer, who is known as a Gauger, for every four to six miles of his district, according to the amount of labor required upon that part of the road.

These gaugers devote their whole time to their section, except that during August they may be granted leave by the local surveyor to help in the harvest, if their section is in a satisfactory condition. They are responsible to the local surveyor for the maintenance of their section, and are visited at least fortnightly by him.

During the autumn and early winter, when the work on the roads is heaviest, they are granted extra help, sometimes having as many as four or five men under them.

PARISH ROADS.

The vestry of the parish at present have had the management of the parish roads, but by the "Parish Councils' Act," lately passed, the supervision is this autumn transferred from the vestry to the parish council.

The number of miles of road in each parish varies from four to seven, and the system of maintenance is similar to that under the county, but upon a smaller scale.

The vestry appoints a parish surveyor, who is generally a small farmer or tradesman in the parish, and he is responsible for the maintenance of all roads within the parish boundaries, other than main roads. He does not devote his whole time to the roads, but continues his calling, whatever it may be, and inspects his section systematically, directing his assistants where to bestow their labor. He must also keep careful account of all moneys expended and received on account of his roads, and for these duties is paid a fixed sum annually.

The amount of labor required on the parish roads varies, as in the case of the main roads, and the surveyor engages men as he requires them.

WIDTH.

The metalled surface of the road should always be of sufficient width to accommodate the traffic being less in the country than near an important town, the minimum being twelve feet and the maximum about forty.

Between the sod borders the width should in no case be less than that necessary to allow two vehicles to pass comfortably, for this purpose fifteen feet being sufficient. Where the width is less than this people cannot pass without turning out upon the sod, and thus cutting up the border, filling the side channel, and carrying soil from the side on to the metalled surface of the road, all of which should be avoided.

Whatever widths are selected for the county and important parish roads they are uniformly preserved, except where a hill or some other local cause makes an additional width advantageous. The borders are well defined by straight lines or curves, the sod being cut back, side channels cleaned, and outlets opened at least yearly. This, besides giving the road a neat and finished appearance, facilitates and lessens the cost of maintenance.

CROSS SECTION.

A good cross section is one of the most important, and at the same time one of the most difficult, things to attain upon a road.

The slope towards the side should be such that the rain flows freely towards the side channels, as the effect of water standing on the road is ruinous, for it not only adds greatly to the wear of the metal, but also permeates and weakens the crust of the road and subsoil.

The effect of too great a slope is almost as bad as the other extreme, for where there is a perceptible pitch the traffic confines itself to the centre of the road, as the only place where the vehicles can run horizontally, and thus grooves which retain the water are worn by the wheels and horses' feet.

By constant attention the English roads have attained an easy curve, principally of a flat elliptical form, and thus, aided by the smoothness of surface, sheds the water with ease.

The amount of fall from the centre towards the sides is greater on hills than at other portions of the road, so as to shed the water rapidly, and thus prevent it running down the hill upon the road and scouring the surface. The fall is least where there are easy grades on the road, and upon the level the fall on a road thirty feet wide is generally about six inches, and should never exceed nine, while for the narrower roads a fall of three or four inches is given.

METAL.

The metal used upon the roads varies greatly, according to the locality and fitness of local supply, if any. Those in most common use are the igneous rocks, the granite being the principal, iron sandstones, flint, flint and chert gravel, the harder limestones, and in the iron district the slag and furnace refuse are used.

In choosing a road material the four properties considered are its hardness, toughness, its power to withstand the action of the weather, and the degree with which it binds. No one metal possesses all these qualifications. Thus, although granite is hard, it is often brittle if containing too much felspar, and of itself does not bind well. Flint also is very hard, but is brittle and is not cohesive, while, on the other hand, limestone from the mortar-like detritus formed by its wearing binds well, but is not of sufficent hardness for roads on which there is heavy traffic.

Returning to the county which we have especially under consideration, there is no local supply of igneous rocks. Where the rocks do outcrop they are chalk, with which is associated flint, and there are also deposits of flint and chert gravel, while upon the seashore large quantities of flint may be procured.

Besides the local materials, a great deal of granite is imported for use upon the county roads.

When gravel is used, it is from pits sanctioned after inspection by the county engineer, and is screened and broken to a certain gauge; being in this condition contracted for per load of twenty-four bushels either in the pit or delivered on the roads. The usual price of this gravel is from $1.10 to $1.20 a load delivered, or 75c. a load in the pit.

The flints are of two classes: first, those gathered off the land, and, secondly, those from the seashore. The former are gathered during the autumn and winter by children off the fields, the children being paid 2c. per bushel, and the landowner sells them at 5c. per bushel, or about $1.40 a load delivered on the road.

The flint from the seashore is not so good a road material as the land flint, the salts of the sea having the effect of softening it, so that when used it should be broken and left standing in heaps or metal depots at least one year before being placed upon the roads. The ordinary flint also improves by standing in heaps after being broken.

Upon the most important county roads granite from Guernsey or Belgium is used. This granite costs according to proximity to a seaport, and on the east coast costs from $3.00 to $3.75 a ton. This is double the cost of the local material, but after careful investigation it has been estimated by good authorities to stand three times the wear and traffic; and is therefore cheaper in the end. It is, on these grounds, favored by experienced men for use on the principal county roads where the traffic is heavy.

SIZE OF METAL.

The most advantageous size to which the metal may be broken depends greatly upon its toughness, and how it is to be laid, but the pieces should be as nearly cubical as possible. The recognized standard for the metal since early in the century has been its ability to pass through a 2½ inch ring, or a cube of about 1½ inches.

A hard material may, with advantage to the road, be broken smaller than a softer one, and if but light repairs are to be made a smaller gauge is an advantage, as the material binds better, covers more, and gives a smoother surface. When the metal is to be rolled, it gives a better and stronger surface if the pieces are large.

In all cases the metal is broken as nearly cubical as possible, and should pass the gauge in every way. When the harder descriptions of metal are used, it is important that they should be as near the same size as practicable, which will give a smooth surface to the road and reduce the wear and crushing.

The granite is delivered broken, being crushed by machinery, while the local material is broken by hand during the summer by the man in charge of the road, or is delivered broken upon the roads.

LAYING THE METAL.

The laying down of the metal to the greatest advantage is an art learned only after long practice, and especially is this the case with light repairs. The tendency of the roadman is, for the sake of appearance, to lay it in long narrow rows, where the horses—whose habit it is to follow in the same track--have worn a hollow, or in the wheel tracks. This causes the traffic to be diverted to the side of the road. The only way to avoid this is to lay the material, where necessary, in short lengths at a time.

The metal should be laid on one stone thick, and close enough so as to touch those on all sides of it, thus forming a sort of mosaic work. Each cube then gives and receives support from its neighbor, and the binding is greatly facilitated.

When the roadbed is thick and strong, it is sometimes an advantage to pick the surface before laying on the new metal, so as to help the binding, but it should never be more than half an inch deep, and is only advisable where a hard metal like granite is to be used, and where the surface has worn unevenly.

A more common plan of aiding the consolidation of old and new materials is by the use of a binding material, marl being now greatly used, especially where the subsoil is of a light or sandy character. After laying the metal the marl is spread over it in the proportion of about 1 to 7.

The use of steam rollers upon the roads is growing rapidly, the county engineer now having four at his disposal, and hopes soon to have twelve, or one for each district of one hundred miles. These rollers are capable of consolidating one thousand two hundred superficial yards of new material per day, but their use is only advantageous where extensive repairs are being made upon roads with strong foundations, and where some thickness of metal is to be laid down.

WIDTH OF WHEELS.

The width of wheels and their loads has been the subject of statutes and by-laws since early in the century. Under the "General Turnpike Act" in the reign of George IV. a premium was put upon broad tires with countersunk rivets by charging them but two-thirds of the ordinary toll. At the same time conveyances with heavy loads and narrow tires were charged additional.

At present there are no regulations bearing upon this subject which are enforced, but wheels upon all vehicles and carts are much wider than those in use upon our roads, and which, especially in soft weather, do so much harm. Upon the carts, which replace our buggies, the wheels average two inches in width, or about twice as wide as those on the corresponding conveyance in use here, while upon the carts and wagons used for farm purposes the width varies from four to six inches.

There is a growing feeling that some measure should again be introduced and enforced, and authorities place the maximum allowable load for a wagon at one ton of vehicle and load per inch of tire, that is, five hundred weight per wheel.

DISTRIBUTION OF LABOR.

The great difficulty in this respect is that the heavy work is concentrated unavoidably into a short time, whilst at other times the road surface itself requires little or no attention.

During the summer months the man in charge should clean out the side ditches, which are too wet at other seasons. He should also take advantage of any soft weather to cut back the sod bordering on the road, thus giving the road surface a uniform width throughout. This keeps the road of the proper cross section, and forms a channel for the storm water between the side ditch and the footpath or metal heaps, and from which it is led at intervals into the side ditch. This should all receive attention before the wet weather sets in. On roads where flint is used and delivered unbroken, it is broken to the proper gauge during the summer.

During the early autumn, or as soon as the rains make it necessary, the roads are scraped to remove the mud produced by the summer's wear of the metal.

Having cleaned up the sides and scraped the surface, the new metal should be laid on, the first care being bestowed upon those places which are naturally low and damp. After these are attended to the remainder receives its coating, and it should all be laid before the beginning of the new year

The new metal being laid, the work upon the road for the remainder of the winter is light, and any extra help which may have been necessary is dispensed with. The regular man's time is occupied in attending to any weak places which may need additional metal, raking the loose metal so as to facilitate its binding, and scraping where necessary.

When the rains of spring, with the wear, tend to again make the road muddy, the gauger's time is taken up with scraping the detritus off the surface, and any spare time should be spent upon the side ditches.

METAL DEPOTS.

To facilitate the metalling in the autumn, the road material, when delivered by the contractor or otherwise, is laid in heaps by the roadside, if its width be sufficient to admit of same. These heaps vary in size and distance apart, according to the importance of the road, in some cases being as close as twenty yards, but should never be more than one hundred yards, which leaves the gauger but fifty yards at most to wheel his material when metalling the road. Upon narrow roads, where this method cannot be adopted, recesses have been constructed on the side, and here the material is stored without inconveniencing the traffic. These stores of road material are known as metal depots.

COST.

The cost to the county for the main roads was last year £35, or about $170, per mile. Of this thirty to forty per cent. is chargeable to manual labor, about ten per cent. to salaries and management, and the remainder to materials. This money is raised by a general rate over the whole county, with the exception of the county boroughs of Norwich and Yarmouth, which maintain their own roads, etc., themselves. The cost of the parish roads is from $60 to $75 a mile per year, and this is raised by a rate upon the incomes of the parishioners.

Having detailed to you the points which most forcibly struck me regarding the English system of maintenance, I think you will agree with me that in many points we may, with advantage, follow their example, after allowing for climatic and other variations of condition.

The three things to which these roads owe their superiority are, first, the stability of their foundations ; second, the constant and not spasmodic attention bestowed upon them ; and last, but not least, the fact that they are under competent authorities in the county engineers and local surveyors.

ISCUSSION.

Mr. Alan Macdougall—This is a useful addition to the literature of good roadmaking, and is presented at a fitting time. The conference held in the Canadian Institute last February resulted in the formation of an association for the improvement of roads, under the name of The Ontario Good Roads' Association, which held a meeting in Toronto in September during Exhibition week. The Provincial Government is taking so much interest in the subject that it is not likely to be neglected, and from what I can learn it is likely to be a prominent subject of discussion at meetings of farmers' institutes this season. There is a danger that the present craze for electric railways will blind rural constituencies and hinder the growth of road improvements; it becomes the duty of those of us who know the value of roads to the advancement of the country to combat the idea that it is not necessary or advantageous to improve sidelines. The country can no more exist without good roads, and sidelines too, than we can breathe without lungs.

I have already pointed out to you that there is a good field for the exercise of your talents in this field of engineering, and I hope it may not be long before many of you are engaged in improving our roads. You are kind enough to ask me to address you once more; I daresay I might be able to do so early next year, and I shall have pleasure in so doing, if I can arrange for a subject.

Mr. P. K. Hyndman—Having already written a paper on the subject, which appears in the first report of The Good Roads' Association of Ontario, printed by order of the Government, it will be unnecessary to repeat here any of the views or statements which are there given. Suffice it to say that it is satisfactory for me to find that the main features of the English system, as described so fully and clearly by Mr. Johnson, but of which I was ignorant, are identical with what I proposed should be adopted in Ontario. These are (1) a special road tax, instead of tolls or statute labor; (2) the administration by county and parish municipalities, with the consequent necessary classification of the roads under each; and (3) the appointment of a competent engineer for each county.

Our road allowances being all laid out, it is necessary, with some exceptions, to adhere to them. Fortunately, the topography of western Ontario, at least, renders it possible to do this, so that alignment has not to be considered, as in Great Britain.

The width of sixty-six feet, also, gives plenty of space for making carriage and foot ways, as well as room for shade trees and stacking "metal" for repairs. I have already described how, in my opinion, this width, which should be fully utilized, may be divided up.

In India, the repairs were carried out by miles, which facilitated the periodical renewal of the upper metal coat. Therefore, I consider it necessary, in the first instance, to mark out all the main roads, at least, by mile posts, or divide them into sections, extending from one cross-road to another, which is generally a distance of 1¼ miles. This is a much better arrangement than renewals in short pieces.

Repairs in India consisted of what were called "annual" and "petty" repairs, the first being the laying down of an entirely new coat of metal every three or four years, or as often as required over the whole mile. The metal for this was brought in and stacked in one continuous heap on one side of the road. For the second, which consisted in patching holes which would appear in the coat, after the first year, the metal was stacked in short heaps, distributed over the mile on the other side of the road.

This work of collection of metal, laying the new coat, and making up the earthen berms was carried out by contract, the patching being done by gangs of monthly-paid laborers, who attended to this, making up the earthen berms and slopes, when and where required.

Mr. Johnson has accurately described the qualities of the different materials used for road metal. Trap-rock is the best. It is used extensively in Scotland, where it is called "whinstone." In Ontario there is not much variety, beyond the ordinary pit gravel. In India, a material much used is an earthy nodular limestone called "kunkur."

This material, after being broken and screened off the earth embedded in the cavities, is laid down and consolidated by iron hand-rammers, plenty of water being used in the process. It binds well, and makes a very smooth road, but is deficient in hardness.

Thirty-five miles of the roads in my division were metalled with sandstone, broken up from large boulders which were brought down every season by the torrents from the Himalayas. A little earth or clay was scattered over this, and dibbled in with light strokes of a pick, and the coat consolidated by a large heavy stone roller six feet in diameter (of which there are several on the road), pulled by about forty coolies or laborers, water being also used in this work. The patching was done by hand-ramming. This road was not nearly as smooth or pleasant to drive over as the "kunkur" roads.

In Central India there is kind of red laterite called "moorum," which is used as a road metal. It is not capable of being blasted, and is very difficult to break up with the pick. It makes a smooth road like "kunkur," but, like it, wears rapidly.

Broken, overburnt, or vitrified brick is also used as road metal, but it is friable, and apt to work loose, unless some binding material, better than clay, is used. Still, if procurable, it forms a fair material for road metal.

I have found the best width for metal was twelve feet, as ten feet caused the traffic to travel in the same track, which wore into two deep hollows or ruts. This was not the case where the metal was twelve feet wide. Near large centres of population the width of metal was increased to sixteen feet. The total width of the carriage-way was thirty feet, as the roads were main trunk roads. The thickness of a coat of metal was taken at four and a half inches, and was laid down according to a wooden "template" laid across the road, the central thickness being about six inches and the sides three inches.

The metal was carefully spread for lengths of about one hundred yards. Before consolidating, as already described, I found it better to repair and bring up the surface on which the new coat was to be laid to a hard, even, and smooth condition, the loosening of it by picks making it too soft, and the new coat adhered perfectly to it. Whilst a length was being consolidated, the traffic was turned aside to the berms, which were afterwards made up to the new level, and not until the new surface was perfectly dry was the traffic allowed to pass over it. Similarly, the patches were cut out in a rectangular form, and filled in with fresh metal, which was rammed and watered, and brought flush with the existing surface.

The practice in Scotland, which was in vogue before the introduction of the steam roller, of spreading the metal over all hollows, and allowing the traffic to consolidate it, was most unscientific and wasteful, as fully half the metal was pulverized before that part of the road became smooth again.

Small patches should be hand-rammed, where the extent of the petty repairs does not warrant the employment of the steam roller.

The Telford system of road surface, providing an underlayer of large stone, has the defect of not giving a firm and even bed for the upper coat of broken stone to rest on.

On laying metal for the first time on a road, it is desirable, besides providing proper drainage, to ram or roll the earthen surface till it is quite hard. It is better that this surface should be flat and not rounded. In India, a new road received two coats, one being consolidated before the second one was laid down. The second coat might consist of stone broken to a larger size, say, to pass though a two and a half inch ring, the upper either two or one and a half inches, the latter being preferable.

Gravel, when used, should be screened and broken to two inches, and one and a half inches in *two* thicknesses or layers for the second coat (the first or under coat two and a half inches), the coarse sand remaining to be spread thinly over each layer, to assist in binding.

After a new coat has been consolidated, very fine gravel or stone dust should be spread over the upper surface to a thickness of half an inch, as "blinding," which makes the new coat smoother to travel over, besides preserving it till it has got quite hard.

Drains should not be *under* the carriage-way, as they may cause subsidence. The edges of the carriage-way should be kept even and trim, and every facility given for the storm water to run off into the side gutters. Where there are slopes, these should be grassed to prevent their being cut up into channels by the rain water.

The general form of cross-section is a central curve of about one hundred feet radius, the side berms sloping off at one in forty tangents.

The planting of trees, and provision of, at least, one footway at the side, and keeping the whole width trim and neat, are very important matters to be attended to.

The time for carrying out the renewals and heavier repairs must be fixed at the most convenient and favorable season of the year, it being borne in mind that where repairs are required to a small extent these should be carried out at once.

The County Engineer should have charge of all the roads, as tending to a uniform system. He should have a sufficient number of assistants and road overseers, according to the extent and importance of the work.

He might also be given charge of the various drainage works in the county carried out under the Drainage Act, and might act as consulting engineer to the municipalities of the smaller towns and villages in the county which could not afford to employ an engineer, but could pay the salary of a street or town overseer. All county and township buildings might also be put in his charge to carry on the necessary periodical repairs. In this way, his time would be fully occupied.

For the guidance of the staff in their duties, a specification and set of rules and regulations, embodied in a code, should be carefully drawn up, printed, and a copy furnished to each member of the staff. These rules can be amended from time to time.

Mr. W. F. Van Buskirk—Mr. Johnson's paper gives us much information of a character not readily obtainable in this country, and which should be of value to all interested in road improvement.

Quantities and prices of material and labor on completed works and the maintenance of them are always interesting to engineers, and it is not often we get them in detailed form.

As Mr. Johnson has made a pretty extensive study of the English roads, it is probable that he can give us a little more information on some few points. For instance, it would be of interest to know what the county and other surveyors are paid for their services, and the manner in which they get over their respective sections of road ; what their duties are in regard to buying material and payments therefor. What about the management and care of water after it leaves the surface of roadways ?

The drainage of the subsoil foundations of roads and the removal of storm waters is, of course, the most important feature to be looked after in the maintenance of a road, and I am sorry to say is the feature most neglected in our own attempts at roadmaking. This neglect of the first necessity of a good road is perhaps excusable in the case of the ordinary citizen, as he does not generally think why a road is good or bad ; but an engineer should know that it is not by chance that the large amount of water delivered on a roadway is removed without doing serious damage. When we consider that some forty thousand tons of water fall annually upon each mile of roadway in this country, the problem of its immediate removal begins to assume some importance, and any hints we may be able to obtain in regard to the practice, in countries having good roads, are of value to us in dealing with our own.

Mr. J. F. Beam—Undoubtedly the first step in this important problem should be the adoption of some suitable plan or system by which, when once in force, good roads would result, and add materially to the comfort and welfare of the people of our province. How can this object be attained with more ease and thoroughness than by taking advantage of the experience of countries which have already worked out this question ?

This paper of Mr. Johnson's plainly shows that we can look to our motherland, England, more especially with profit and advantage in regard to road management, as well as in many other respects in which she stands so pre-eminently foremost among nations in the science of government.

Having observed and studied this question for years, my conviction is that before any system is crystallized into law we ought not only to avail ourselves of England's experience, but the experience of all other leading countries and of the foremost states of the American Union where improved modern methods have been adopted should first be obtained, and placed as far as possible before our people by the aid of public meetings, which should be held in every county and township to discuss the most suitable method for each locality, and upon the result of these a general system may be devised. Caution, however, is very necessary, as this matter should not be hastened until public opinion is quickened, and the agriculturists especially become ready to handle it in earnest.

Such a movement, I am glad to state, has already been planned by the executive board of The Ontario Good Roads' Association, where it was proposed at the meeting held lately in Toronto to send the best available speakers on this subject to address the farmers' institutes in January.

I am well aware that at present the farmers generally are adverse to adding any further burden of taxation, and it must be fully shown that a better system need not prove heavier, but rather less burdensome, than the present wasteful and inefficient statute labor system, more especially if the English income tax method were adopted, as the man who has the smaller income need not pay so much as the man with a larger one, who also gets proportionately with his large business more benefit from improved roads.

During the summer the clay roads of this district are excellent, but they are almost impassable during the rainy seasons of spring and fall, and also during an open winter.

Mr. S. M. Johnson—Mr. Van Buskirk's questions touch upon some important matters which have received but little notice, or been omitted in the paper.

Regarding the salary of the county surveyor no fixed rule is followed in England, as the size of the counties and responsibilites vary, and he is paid for his services according to the work he is called upon to perform. Passing to the local surveyors, it must be remembered that these men are not surveyors in our sense of the word, but are simply inspectors, or overseers, who have received a thorough knowledge through practise of road building and maintenance. These men are paid about $500, a year, and in many counties they receive an allowance for the maintenance of a horse and cart, as it is in this way that they inspect their district.

As to the respective duties of surveyors in purchasing material, etc., the county surveyor prepares an estimate each year showing quantities of material and labor required for the following year, and appropriation necessary to carry this out. When sanctioned by the council, tenders are called for the material and cartage, and, as required, the county surveyor orders from the accepted tenderer.

In regard to the management of water after leaving the road surface, in the open country a well-kept open ditch is maintained upon one side of the road, at least, and this empties into the natural watercourse at the most convenient point. The "General Highways Act" of 1835 granted the authorities power to seek an outlet through the adjoining property to the watercourse, the owner being compensated for any damage caused. The same act also provides that if any watercourse be obstructed the surveyor shall order the occupier of the land to clear it, and if he does not comply the work may be done by his own men. As the road approaches a village or town, covered drains take the place of the open ones.

Where the subsoil requires drainage beyond that given by the side ditches, drains are laid with open-jointed pipes, these often taking the form of mitre drains; that is, they meet in the centre in the form of a V, and run with an inclination of about 1 in 100 towards the side ditches in the direction of the fall in the road.

VICE-WORK

By G. M. Campbell, '96.

Under this heading will come all operations by the machinist which are not included in the work done by machine tools.

The man who performs vice-work is generally known as a vice-hand or fitter; he should have a good mathematical education, and should, of necessity, be a man of good natural ability, for new classes of work, new ideas, original designs, are being continually brought forward, and for these the workman has always to be prepared.

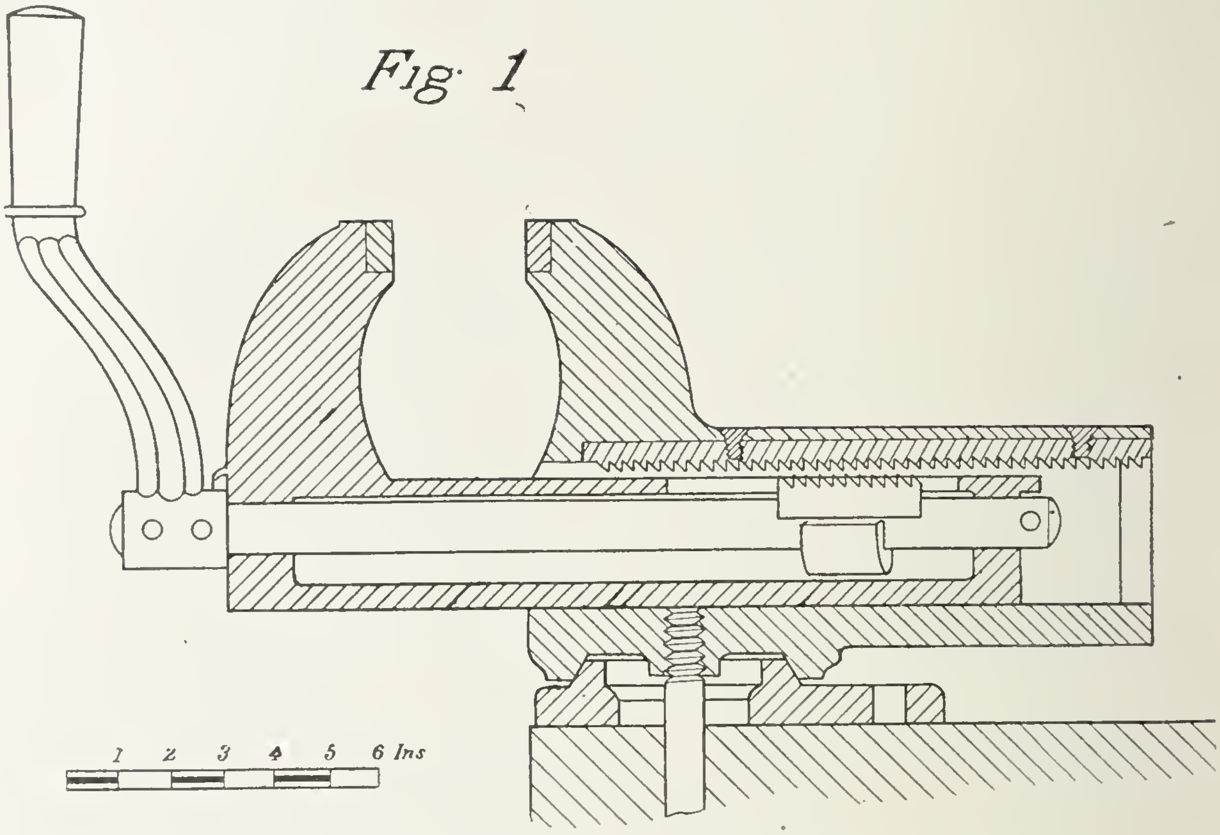
The number and variety of tools that a fitter requires is quite limited, but the number it is advantageous to have is not. Among the necessaries are an ordinary two-foot rule, a twelve-inch scale, divided on one edge into sixty-fourths, two or more pairs of outside, the same of inside, callipers, compasses, surface gauge, spirit level, scriber, and try-square. Other handy tools are a pair of compass-callipers, or, as workman say, a pair of "morphodites," bevel, centering, box, and T squares, bottoming gauge, thread gauge, pair of trammels, plumb-bob, and many others. In addition to these tools a fitter should have or have access to a bench-vice, hand-vice, hammers, chisels, punches, drifts, files, file-card, scrapers, hacksaw, taps and dies, reamers, surface plates, straight-edges, etc.

It is thus easily seen that the term "vice-work" is of the widest significance. It includes, besides the direct treatment of the work by chipping, filing, scraping, polishing, etc., the proper use of all the various hand tools and instruments mentioned; the lining and marking off of articles of every description, to prepare them for further manipulation; the final fitting and erecting into one symmetrical whole the various parts of the simplest or most complex machine. But of these various requirements the present paper will take up vice-work in its most limited sense, the writer deeming it better, in such a short paper, to touch somewhat definitely on a few main points than to skim vaguely over the whole wide subject. Attention will therefore be mainly directed to the form and general use of the vice, hammer, chisel, file, and scraper.

VICE.

Of necessity, the first thing that has to be looked to is the vice. One of the best forms in the market to-day is that patented by Entwisle and Kenyon, Fig. 1. These vices are on a swivelling base, so that they can be swung round and locked in any position, usually by a large winged nut underneath the bench. The jaws are steel-faced and are parallel in all positions; the front jaw is part of a sliding box which may be easily hauled out and in when the handle, or rather lever, is vertically upward. The locking device is quite simple; in the body of the vice above the sliding box is a rack with fine teeth, eight to the inch, pointing to the back; the handle is fastened to a rod, extending the length of the sliding box, pinned at the back end to prevent its abstraction and to prevent it making more than three-quarters of a turn, and on this rod toward the back end is an eccentric running spirally or screw-wise around it; on the eccentric rests a short toothed steel piece, the saddle, shaped beneath to fit the slant sides of the eccentric. When the handle is up, the saddle, the teeth of which point to the front, is just clear of the rack teeth; as the handle is lowered, the saddle is raised, the teeth engage, then the screw motion of the eccentrics hauls the jaw firmly to its grip. The usual closure is about one-eighth of an inch. To grip any article, raise the handle with the right hand, haul out the sliding box with the left, place the work in position, push in the jaw till it presses against the work, then

Fig. 1



rapidly lower the handle and the work is firmly and quickly gripped. For rapidity and ease of action and firmness of grip this vice has no equal, for with one-half turn of the handle an article of any size, large or small, can be securely seized.

The height of the vice from the floor depends much on the class of work that has to be operated upon; if heavy, it should be low; if light, high. A good average height is to have the jaws of the vice on a level with the workman's elbow; usually, however, the height depends solely upon the height of the bench, which should be about thirty-three inches.

Of the ordinary vices, those with a sliding box are better than leg-vices where the front jaw is long, acting with hinge motion; therefore, its jaws are parallel and vertical in one position only. For heavy irregular-shaped work the latter, however, acts very well.

To prevent injury to the surface of the work from the hard and rough jaw vice-clamps are used, made of copper, for holding iron, and of leather or lead for brass or any delicate piece of work. The copper clamps should be of one-sixteenth inch annealed sheet copper, shaped by the hammer to fit neatly over the vice jaws; the jaw part of the lead clamp being about one-half inch thick. For holding articles of special shape various attachments are used; thus, for holding a taper cotter, a piece of iron, straight on one edge and rounded on the other, is pivoted to a piece of copper which fits over the back jaw of the vice (Fig. 9), the cotter beds itself against the forward jaw and the straight side of the vice-strip, which then readily adjusts itself against the fixed jaw by reason of the rounded side. An excellent way of holding small screws or other articles is made by connecting two pieces of iron or copper by a spring (Fig. 10), the pieces being provided with a flange to rest on the top of the vice jaws, and having in the face of each, vertically, round and square grooves of different sizes. The spring keeps the pieces slightly apart until the jaws of the vice tighten upon them.

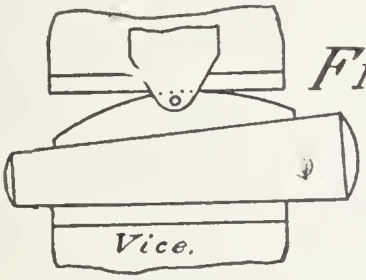
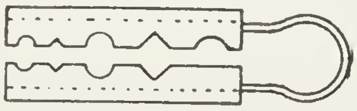


Fig 9

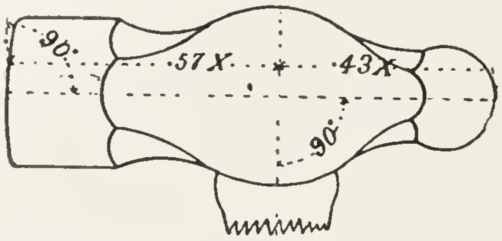
Fig 10



HAMMERS.

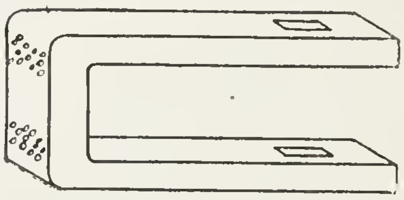
Hand hammers are divided into two classes, (*a*) chipping and riveting, and (*b*) pening. In the former (Fig. 2), one end is cylindrical in shape, the other, hemispherical; the first for chipping or driving, the second for riveting; while in pening hammers the round knob is replaced by a long narrow edge, either straight or rounded in its length, the edge being either at right angles or parallel to the line of the handle, the former being much the better. Hammers vary in weight from 6 to 30 oz., according to requirements. One for general work should weigh about 21 oz., having a handle 13½ inches long, inside the head. The proper dimensions of a hammer of about that weight are: length over all, 4⅛ inches; length of face end, ¾ inch; diameter of face, 1¼ inches; length of eye, 1½ inches; thickness at eye, 1⅛ inches; the pene, ⅞ inch in diameter. The face of the hammer should be slightly convex, with rounded corners.

Fig 2



A hammer weighing 28 oz., with 15-inch handle, is very serviceable for heavy chipping or driving. In fitting the handle, it is most important to have it stand at right angles to the axis of the hammer head (see Fig. 2), and to have its oval true with the axial line, otherwise erratic hammering is sure to result, with injury to the hammer, the work, or the workman's fingers. The operation of pening is much resorted to to straighten articles which have become bent, or to bend pieces of work to give them a different shape, as shown in Fig 3. It consists in hammering the skin of the metal, thereby lengthening it. If a straight piece be hammered all over one side, it becomes convex on that side; if a curved piece be hammered on the convex side all over the surface, the curve bends to a smaller radius, but, if hammered on the inside, to a larger radius. Ham-

Fig 3



mering in one place, instead of all over the surface, will produce a sharp instead of a uniformly curved bend. The amount that cast iron can be bent is considerable. The hammer should not, in general, exceed 8 oz. in weight; and, in hammering, most of the motion should come from the wrist, as much more depends on the number than the force of the blows. When pening cast iron, it is best to rest it on a narrow surface of iron, always taking care to have the article bedding well when being pened. Articles of other material are best done when resting on wood. When any article has been pened, as little of the surface as possible should afterwards be removed, for, otherwise, the results of the pening may be destroyed.

Riveting is generally performed by the machinist upon cold metal, and can best be described by an example. A crank pin has to be riveted to the crank (Fig. 4), the crank first being countersunk on the back (a narrow and deep countersink will hold much better than a wide and shallow one), and the pin, which should be slightly longer than the thickness of the crank, should be recessed. Stretch nearly the whole end of the pin, deliver the hammer blows in a slanting direction from the centre to the circumference, thus forcing the metal outward. The pin should be hammered symmetrically, *i.e.*, first on one side of the centre, then on the other, which will prevent its being thrown out of true. The round pene of a light hammer should be used, but the weight of hammer varies with the weight of the article operated upon. The article to be riveted should rest firmly on a solid bed, such as an anvil, a piece of copper being interposed if the work is liable to be injured by the contact.

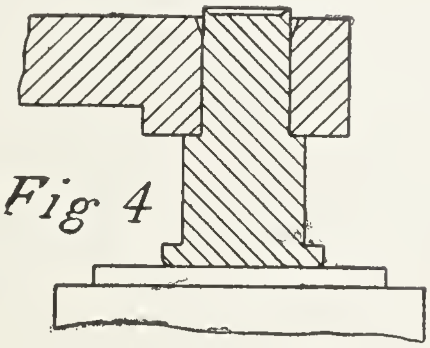


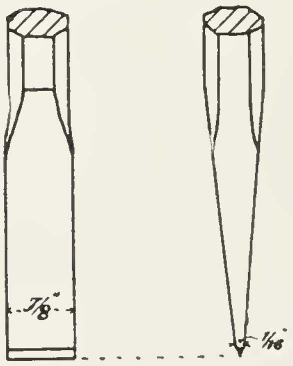
Fig 4

Hammers are used for driving, straightening, and stretching. In driving, a sharp, rapid blow is much more effective than a slower one with the same momentum; for example, in loosening a key from its seat, unless the blow produces the desired effect, it simply makes matters worse by swelling the end of the key; in stretching, as in pening and riveting, slower "dead" blows act better, while in straightening the kind of blow depends on circumstances, slow blows with a fairly heavy giving good results. When using a hammer, to get a maximum amount of work from it, hold it, at the end of the handle, somewhat freely, by no means grip it, give plenty of motion to the wrist and fingers, so that when the hammer is drawn back the pene all but strikes the workman's elbow ; let the force of the blow be mainly derived from the forearm.

CHISELS.

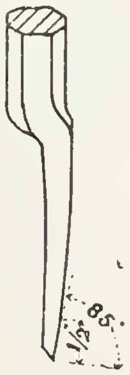
Chisels are of all sizes, from a small one driven by a four-ounce hammer to a large one driven by a fourteen-pound sledge ; but for all ordinary sizes and shapes three-quarter-inch octagon steel is used. These chisels are of various shapes—flat, side-cutting, cope or crosscut, keyway, round-nosed, cow-mouthed, diamond-pointed, oil-groove, and draw-chisels, and many others. The greatest of care should be exercised in tempering chisels, for the work required of them is considerable, the temper extending for half an inch or more from the cutting edge, and being in color from a yellowish brown, for light cuts on hard steel or iron, to almost a blue, for heavy cuts on wrought iron ; a dark red makes a very serviceable tool. However, the Society is to receive, soon, a paper on the subject of tempering, when the matter of tempering will be fully dealt with.

Fig 5



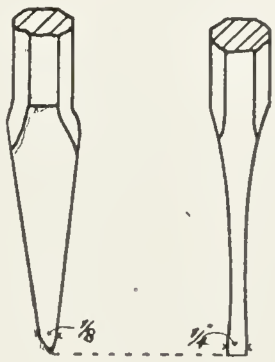
The flat chisel (Fig. 5) is the one most used, and should be made shorter than is usually the case, $6\frac{1}{2}$ or 7 inches being quite long enough. It is tapered for from 3 to $3\frac{1}{2}$ inches of its length, and is about $\frac{1}{16}$ or $\frac{3}{32}$ of an inch thick near the point, and about $\frac{7}{8}$ of an inch wide. The facets forming the cutting edge should be flat, not rounding, so as to form a guide to maintain a proper depth of cut. The angle of the facets to one another depends on the material and on the heaviness of the cut ; the lighter the cut, the more acute the angle ; the tougher the metal, the greater the angle. In general, 65° to 60° for cast steel, 60° to 55° for wrought iron, 55° to 45° for cast iron, and 45° to 35° for brass and copper ; the facets being ground at an equal inclination to the axis of the chisel. The cutting edge should be very slightly rounded in its length, nearly straight in the middle, slightly more rounded close to the corners. The rounded edge gives increased strength, as the corners are not so apt to break off; but, if the edge is quite straight, better and smoother work can be done; a chisel with a straight edge is, therefore, used to advantage whenever there is clearance to its corners. The edge should be carefully ground parallel to the flats, and perpendicular to the length of the chisel; for, if not, in the first case, the chisel would cut deeper at one side than the other, and, in the second, it would be apt to jump sideways after each blow.

Fig 6



A side-cutting chisel (Fig. 6) is a slightly altered form of flat chisel; the taper is all on one side, as is also the grinding for the facet angle, while the other side of the chisel is nearly straight, being bevelled very slightly only for about ½ of an inch from the cutting edge. This tool is used very much for cutting down the side of holes, such as the cotter holes in a connecting rod.

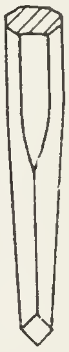
Fig 7



The cope or crosscut chisel (Fig. 7) is for cutting narrow channels across any surface; it is, in length, about the same as a flat chisel, drawn out somewhat heavier, *i.e.*, the taper is shorter. The cutting edge is usually about ¼ of an inch wide, and the cutting angle slightly greater than in the case of the flat chisel, the bottom facet being at a less angle than the top to the axis of the chisel. It should be widest at its cutting edge, decreasing very slightly the first $\frac{1}{4}$ of an inch, and, after that, more. The first $\frac{1}{4}$ of an inch guides the chisel, yet, at the same time, allowing it enough motion sideways to permit its being properly directed. It is even more particular in the case of this chisel that the cutting edge be ground properly, as it should be at right angles to the flat sides and to the line of the chisel.

Keyway chisels are special sizes of cope chisels, and are of fixed widths, usually $\frac{1}{64}$ of an inch less than the width of keyway required. The greatest width that may be used to advantage is about $\frac{39}{64}$ of an inch, *i.e.*, for a $\frac{5}{8}$-inch keyway; keyways of greater width being made by two or more cuts of a narrower chisel.

Fig 8



The diamond-pointed chisel (Fig. 8) receives its name from its shape. The steel is drawn out till almost square at the point, then bevelled from corner to corner, the point being usually on a line with a side of the tool, and the two sides forming the cutting angle should be about 85° to each other. This chisel is used for cutting out square corners in a round hole, for cutting a heavy iron pipe in two, or a thick sheet of metal, etc.

The other chisels are governed in shape by the same general principles; their use is known from their general appearance; for example, the oil-groove chisel is a round-nosed narrow chisel, curved in its length, which adapts it for use on the curved surface of bearing brasses, etc. When any article has to have a cut taken off one surface, the operation should be performed as follows:—Mark the line to which the cut has to be taken, and bevel the edges all the way round with a chisel, finishing to the line with a file, which will prevent the metal breaking away at the edges; next groove the surface, almost to the lines, with a crosscut chisel, leaving $\frac{3}{4}$ of an inch between the channel, and then remove these ridges with a flat chisel, in at least two cuts if on cast iron, for, in taking a heavy cut on that material, the iron is apt to break away below the line of cutting. On wrought iron, use a little oil on the end of the chisel.

When taking a light cut or using a narrow chisel, hold the chisel well to its cut, *i.e.*, keep its cutting edge always against the metal and the shaving; but in heavy chipping, with a flat chisel, a "rebound motion" is best, *i.e.*, after every blow of the hammer draw the chisel back a little, then forward again before the next blow, just as if it rebounded under the force of the blow; in this way one can watch better the cut being taken, and can always ensure the cutting edge being properly placed in regard to the chipping.

When chipping stand well in front of the work, so that the hammer acts as nearly as possible in a vertical plane. Hold the chisel loosely; a beginner has to be told this but once, for he soon finds out by experience that if he grips the chisel like a handspike and happens to miss the end of it with his hammer onerous consequences follow, while if he held it freely the hand would give before the hammer, and little damage would result.

FILE.

After the chisel naturally follows the file, the proper use of which is of the greatest importance. Files are either hand cut, *i.e.*, cut by hammer and chisel, or machine cut, the former being much superior. The objection to machine-cut files is an odd one, the teeth are too regular, thus causing the file to cut in grooves. A file is fully described when its length, "cut," fineness, contour, and cross-section are known.

The *length* is measured exclusive of the tang. Hand files are rarely less than 1½ inches or more than 20 inches long; their length does not, in general, bear any fixed relation to their width or thickness.

In "cut," *i.e.*, the way in which the teeth are placed, a file is single, double, or rasp (the last is but little used, and so need not be taken account of). The single-cut file is one in which the tooth extends the full width of the file, being cut by a single course of chisel cuts each parallel to the preceding, all inclined at an angle to the central line, varying from 5°, on brass, to 20°, on harder metals. Double-cut are those having two courses of chisel cuts, one crossing the other; the first, the "over-cut," is inclined at from 30° to 50° to the central line, up to the right; the second, the "up-cut," at from 5° to 30° to the left, the lesser angle giving the better satisfaction; the up-cut is usually slightly finer than the over-cut. Single-cut files are used in all lathe work, and at the vice in filing any narrow edge, and for draw filing on soft metals. Half-round files are usually single-cut on the round side, as are also round files, the edges of flat files, etc.

Double-cut are by far the most used; they cut faster, easier, and smoother, and are suitable for any description of vice-work. The teeth on a double-cut file are, approximately, diamond pointed,

In *fineness*, files are divided into six grades, rough, middle, bastard, second-cut, smooth, and dead-smooth; the distance between the teeth in each case altogether depending on the size of the file, the teeth of some dead-smooth files being so fine that the eye finds it difficult to distinguish the lines: and yet these are cut by hand, the finest coming from Switzerland.

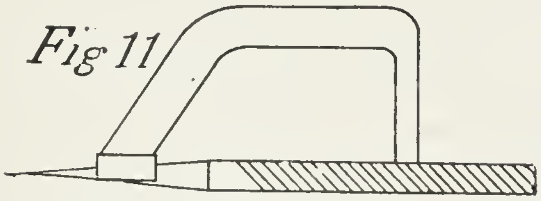
As to *contour*, *i.e.*, the general outline, files are parallel, equalling or bellied, and taper. Parallel files, *i.e.*, those of the same diameter or thickness from end to end, are but little used; occasionally long square parallel files are of service, as, for example, in filing out a long keyway; but the great trouble with these, and, in fact, all files, is to keep them from warping in the hardening; the variation from straight is more noticeable, however, in parallel files. Equalling or bellied files are by far the best for general purposes, for, as these files are slightly thicker and wider at the middle than at either end (the more even the curvature, the better the file), it is comparatively a simple matter to obtain a flat surface. Nearly all "flat" files are equalling. Taper files are those which have a marked difference in thickness and width at the centre as compared with the ends, especially the point, and in this class are included most round files and many half-round and square, and also all triangular files.

In *section*, files are flat, square, triangular, round, and half-round. A flat file is one of any rectangular section other than square. The other terms are self-explanatory. Square files are usually double-cut and well bellied, one edge usually being made a safe edge. The square files and round, generally used, are bastard-cut. Small round files, $\frac{1}{4}$ of an inch and under, are called rat-tails.

There are many other specially shaped files other than those mentioned, but they do not come much into use in a machine shop.

The flat bastard file is the general-purpose file of the shop, any coarser grade being used on soft metals alone or on very large work. For heavy filing, a 14-inch file is used, while for lighter work a 12-inch one is quite large enough. Unless the work has to be polished, the bastard file will usually answer, for any good workman can file quite smoothly with it; a second-cut is, however, used in preference to a bastard when the material is unusually hard, the two finer grades of files being used chiefly for polishing. When the surface to be filed is wider than the length of the file, a surface handle is used which fits over the top of the file, the tang fitting into a dovetailed groove in the back end of the handle (see Fig. 11).

Fig 11



Whenever it is necessary to use a file in a corner, one side of which must not be injured, a "safe edge" is put on the file, *i.e.*, the teeth are ground off; in this way a good square corner may be obtained. Sometimes the edge is left uncut, but in that case also the safe edge should be reground. When the file is pushed end-wise the operation is called "cross-filing"; and when it is moved in a line at right angles to its length, it is termed draw-filing. In heavy cross-filing the file should be held so that the handle presses against the palm of the right hand, thumb on top, while the left hand presses down on the point of the file, the ball of the hand on top, the fingers underneath. If, however, the file is thin, the point should be held with the thumb and one or two fingers, the fingers being nearer the point than the thumb, which exerts a downward pressure, an upward pressure being applied by the fingers underneath, thus tending to make the file convex on the bottom side. As any file can cut on the forward stroke only, remove all pressure from it on the return stroke; otherwise the teeth are apt to break off. For heavy cross-filing the workman should stand well off from his work, feet wide apart, left foot forward, and with each stroke of the file relieve the left foot of all pressure, lean forward, and thus make the weight of the body aid in pushing the file. At the end of the stroke the left foot should receive the weight of the body till the workman has regained his position ready for the next stroke. In all cross-filing, no matter for what purpose, the file should be given considerable lateral as well as forward motion, better results being obtained when it is from right to left, for the file cuts better, and there is less injury to the teeth, but the file marks should cross and recross each other every few strokes. In filing any narrow surface the file should be applied very diagonally. The beginner will find it an exceedingly difficult matter to file *flat*, for, despite his best efforts, he will find that he has, even on a surface three inches wide, considerable curvature. The reason of it is evident: certain pressures are applied at each end of the file, therefore as the file advances, if the pressures are maintained, the resultant of all the forces is continually changing its position, thus causing the file to dip first on one side, then on the other, the result of which will be a curve which by no means conforms to the equation $y = mx + c$. To counteract this, the pressure exerted by each hand must be continually altered, the one decreasing as the other increases. No amount of explanation can, however, make a man file flat. It is an accomplishment in which one can become proficient only after considerable experience.

Draw-filing is employed for two purposes: first, to ensure a much better fit than can be obtained by ordinary cross-filing; and, secondly, to finish the surfaces more smoothly, so that they may be polished. Before draw-filing any article, first cross-file it with a file not coarser than a second-cut. The greater accuracy obtained from draw-filing arises from the fact that it is possible to remove metal just where desired; the curved form of the file allowing it to rest just where it is wanted, and strokes of the proper length can, of course, be given. Thus choose a well and evenly-bellied file, run your eye along the edge, noting the place of greatest curve. Apply that part to the work, grasping the file at each end, independent of the handle. Use short strokes, and when draw-filing in preparation for polishing use light pressure, relieving the file entirely from pressure on the return stroke. Very great care has to be taken to prevent the file "pinning," *i.e.*, getting the cuttings locked in the teeth, and thus causing scratches. As a cause for pinning, long strokes and failure to remove the pressure on the back stroke are most conducive; therefore avoid such. Keep the file flat on the work, not tilted to one edge, except for rapid first touches, or when perfect freedom from scratches is not a necessity. After every few strokes clean the file by lightly tapping it on the back of the vice, and occasionally with a file card, and at the same time blow off the filings from the work, or wipe them off with a *clean* piece of waste, but by no means use the hand for the purpose, for it puts a scale on the iron which it is diffcult to make any but a new file touch. As another preventive of pinning, the surface of the file is rubbed with chalk; this causes the file to cut smoother, but not nearly so rapidly; the file has to be as frequently cleaned as before and re-chalked. The file card is brushed along the line of the teeth, so that the wire may reach the bottom of the grooves. To remove any pins which may get in the file teeth, use a piece of sheet brass, or wire flattened out, which, after being shoved over the file a few times, gets teeth cut in it, which easily dislodge the objectionable cuttings or dirt.

When draw-filing in preparation for polishing, it is best to make the file marks cross and recross each other, and, if possible, across the grain of the iron. The subject of polishing is a wide one, and cannot be entered upon here, but, in general, for very fine work proceed as follows: After preparing the work with a bastard or second-cut, cross-file, then draw-file it with a smooth file, then repeat the operations with a dead-smooth one which has been considerably used, and then finish the surface with emery cloth, either dry or with oil.

When it is necessary to use a round or half-round file, choose one well tapered or bellied, and of a curvature in cross-section less than the curve to be cut. When cross-filing with either of these files give them a side sweep as well as a forward motion, this is given by gradually twisting the wrist; the sweep should be first from right to left, and then from left to right. Avoid, as much as possible, draw-filing with a half-round file, for the teeth are rarely cut accurately enough, and scratching is sure to occur; but if draw-filing is resorted to, slightly rotate the file at each stroke, and give it a little end motion, the marks crossing and recrossing.

Hold all work as close to the vice jaws as possible, and in such a position that the file acts in a horizontal plane.

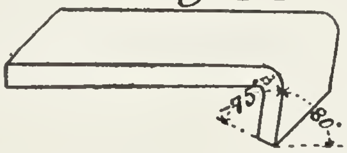
To get a maximum amount of service from a file, it should be used first for copper or brass, then, when too dull for these, on wide to medium surface of cast iron, then on wide to medium surface of wrought iron, and, finally, for any other purpose. Also, to increase the life of a file, be careful always to use first an old file until the hard scale is removed; on any hard spots use the edge of the file.

Well, so much for the files and filing; let attention be next directed to

SCRAPERS AND SCRAPING.

Scraping is the third graded step in localizing abrasive action, and with the use of the scraper an almost perfect surface or bearing can be produced. Scrapers may be divided into two classes: those for flat surfaces, and those for round or curved surfaces. Of the first class there are two main forms, each claiming superiority; they are, first, the ordinary straight scraper, straight throughout, made from a flat piece of steel; and, secondly, a scraper with the cutting edge on a part at right angles to the rest of the tool, Fig. 12. Of these two the writer prefers the former;

Fig 12



it will cut faster, truer, and, if carefully ground, just as smoothly as the other; its operations are much more easily watched and guided, and it can be made and sharpened with far less trouble, and for one sharpening presents two cutting edges, while the second form has but one. As good a scraper as desired can be made from an old flat file drawn out, from which the teeth have first been carefully ground, for otherwise it would be apt to crack in the hardening or scratch afterwards. Scrapers should, of course, be made as hard as fire and water will make them, and for not more than $\frac{1}{4}$ of an inch from the point. The width of the straight scraper at the point should be about $\frac{7}{8}$ of an inch, its thickness $\frac{1}{16}$ of an inch, thickening gradually up to the butt, and its length should not exceed 7 inches exclusive of the handle, for which an ordinary file handle will answer. The end of the scraper should be sharpened on the side of an emery wheel, being made almost straight in the length of the cutting edge. Each cutting edge, which at first contains an angle of 90°, should be carefully oil-stoned to contain an angle of about 95°; this is done to prevent the scraper "chattering," as it otherwise would do. The scraper bent at the point has the front face at an angle of from 80° to 90° with the top of the scraper, and the bottom face at a considerable angle, say 75°, with the front; the angular projection should not exceed $\frac{1}{4}$ of an inch. (See Fig. 12.) When scraping, grasp the scraper firmly, for considerable pressure has during the first processes to be used, and, as in the case of the file, relieve the pressure on the back stroke. Short strokes crossing and recrossing each other should be employed. When planer or file marks have to be removed, scrape diagonally across them, and it is advisable always to give lateral as well as forward motion, as the scraper will cut faster and smoother.

When work has to be scraped flat, a surface plate is necessary; it should be of a comparatively thin plate of cast iron, heavily ribbed, and should be supported at three, and only three, points. To use the plate, "marking" is required, which is usually red lead, mixed to a thin paste with lubricating oil. (Venetian red is better, but is more expensive.) The marking is usually applied with an old rag rolled over and over, and tied with a string so as to form a kind of brush; but when the coating has to be very thin, the palm of the hand should be used. The amount of marking required depends upon the fineness of the work, varying from a thick coating for testing chipping to an almost imperceptible amount for fine scraping; if much red lead is employed for scraping, it is impossible to obtain a true surface. So by no means believe in the maxim, "Much red lead makes a good bearing." Have the marking evenly spread over the surface of the plate. If the work is large, the surface plate should be applied to the work ; but, if not, the work should be applied to the surface plate. Take the article which is to be operated upon, and plane or file it to as flat and smooth a surface as possible by planing, or cross-filing. If a file is used, the work could be frequently tested with a straight-edge, applied to various parts, and then the work is laid on the surface plate to see if there is any "rocking," which should be removed with a file. Next, with a scraper remove the surface of the metal almost to the bottom of the file or tool marks, using short strokes, as mentioned before, crossing and recrossing each other ; then laying the work on the surface plate, and holding it somewhere near the centre, move it lightly about, rotating it at the same time. The higher spots will be marked with the red lead ; the darker the spots the harder the work bore upon the plate. Scrape the work when necessary, *i.e*, whenever the marking shows, removing most metal where the spots are darkest ; again lay it on the plate, and again scrape where required. These operations have to be repeated over and over, till the job is complete. Any well-scraped article presenting about 12 square inches of surface should be able to lift up by surface contact alone a 45 lb. surface plate, each having been rubbed with the hand until almost quite dry.

If the work is held in the vice, be most careful to so hold it that the pressure of the vice jaws does not throw it out of true, and it is remarkable how little pressure is needed to bend even massive castings ; for example, a surface plate supported at *four* points can easily be proved to bend in several ways, merely from its own weight, according to which three of the four feet are acting ; of course the deflection is small, but still quite perceptible ; this is a fact not generally noticed.

If work has to be scraped where a surface plate cannot be conveniently applied,.other methods have to be adopted ; for example, in a valve seat, first scrape the valve to a perfect surface, and then true the valve seat, using the valve as a surface plate.

When scraping wrought iron, steel, or brass, use a little water, by which scratches or chattering are greatly avoided. With brass the cutting edge of the scraper should contain an angle of about 100°.

When it is desired to scrape the inside of a hole or the inside of any curved surface a half-round scraper is employed, which is made usually from a half-round file drawn out to a point, and then slightly and evenly curved on its flat side, having a little more curve than a well-tapered ten-inch square file; too much curve will cause chattering. The cutting edges are along each side, and form an angle with the flat side of about 75 or 80 degrees. The scraper should be hardened "right out," then carefully ground and honed. The scraper should be given a twisting motion, under considerable pressure, and at the same time end motion either inwards or outwards.

The triangular scraper, usually made from a three-cornered file, ground to a point, is used in holes of small diameter or on other small curves, and is worked similarly to a half-round scraper.

THE COUNTRY ROADS OF ONTARIO

By John A. Duff, B.A., Grad. S.P.S.

The following paper has grown out of what was originally intended as a discussion on Mr. Johnson's excellent paper on "The Maintenance of English Roads." My object was to supplement his paper by showing to what extent the system which has produced such good results in England would be applicable to the conditions prevailing in Ontario, and how nearly we may expect to approach in our own country roads the perfection of the English highways.

It was thought, however, that as this was a subject of personal interest to all the members of the Society, it would be well to give full opportunity for discussion by publishing these remarks as a separate paper. This decision having been arrived at, I have incorporated some new matter and recast the whole, but without losing sight of my original purpose; and, as every paper must have a title, this has been called

THE COUNTRY ROADS OF ONTARIO.

At certain seasons of the year, most of our country roads are very bad; some of them are bad at all seasons. Being nearly all earth roads, with no more grading than was incidental to the construction of side ditches, the quality of the road in each case depends in a great measure upon the nature of the soil and season.

This is a very primitive state of things; and it is not surprising that travellers, and especially wheelmen, who have walked through sand ankle deep, or toiled through clay which only needed underdraining, or jolted over some neglected corduroy, should complain of the condition of our roads and demand their improvement.

But, all things considered, are they not much better instead of worse than might have been expected? It is not many years since they were hewed out of the forest. The road allowances went up and down hill, over swamps and streams, following the lines run by the surveyors, without any regard for the two cardinal principles of road location—economy of construction and convenience of travel. This great mistake made the construction of the roads exceedingly difficult in many localities, and has added enormously to the cost of maintenance, to say nothing of the comfort and the beautiful picturesqueness which a level winding road affords. This system of road allowances may have been convenient in the arrangement of farms, but in the hilly country it was fatal to the interests of good roads. And would it not have been a more sensible plan to have laid out the farms with regard to the configuration of the land, instead of having them contain a fixed number of acres? How often do we see a narrow strip of land separated by nature from the rest of the farm, which would be much more valuable if belonging to the adjoining property!

If a more scientific system of road location had been adopted, the problem of road improvement would be much less difficult and less urgent than it is to-day.

Much could yet be done to retrieve the blunder by closing up unnecessary roads, opening out new roads, and making deviations in difficult places.

On these road allowances the pioneers were left to build and maintain roads in the intervals between the clearing of their fields. The roads were only beginning to show the labor which had been done upon them when the era of railway construction began, and they were called upon to build railways instead of highways to connect them with the world outside. They could not well do both. They chose to develop the railways in preference to the highways, but the liberality with which the railways were bonused shows that the farmers appreciate the advantages of good avenues of transportation, and will not be content with bringing the world's market to the nearest town, but will complete the work by bringing it to their own doors.

Now that the province is well supplied with railways, public attention is turning towards the highways, and a few years will see a great improvement in them, unless the electric railway promoters persuade the farmers to build trolley lines instead.

The agitation for the improvement of the roads has already taken definite shape, and in February last the Ontario Good Roads' Association was formed. The report of their meeting, published by the Ontario Department of Agriculture, shows that, though few definite conclusions were arrived at, some valuable papers were read, and much profitable discussion took place.

The feature of the meeting was the vigorous attack made upon the statute labor system. It was called antiquated and unscientific, obsolete and semi-barbaric; but the association did not agree upon any better system, nor upon the kind of road which is both desirable and possible in Ontario.

The latter question should be decided first, because the system of maintenance best adapted to one kind of road may not be the best system for some other kind.

In most localities in Ontario the choice will be between Earth, Gravel, and Broken Stone or Macadam roads.

EARTH ROADS.

The most prominent characteristic of earth roads is their infinite variety, ranging all the way from a wagon track across a common to a road as carefully graded and drained as for Gravel or Macadam, though without a metal covering.

Nearly all the country roads in Ontario are Earth roads, and very few of them are as good as they might be, the chief cause being that little or no attention is given to underdraining.

An instance which has come under the writer's observation is that of a place near the foot of a hill, which had a very unpleasant habit of "breaking out" every spring. Some years ago, under the direction of the pathmaster, the road at this place was paved with field stones, lightly covered with earth. Last spring it was impassable, and a sign had to be put up to warn travellers. It had "broken out" in a fresh place. A few rods of tile drain, at a cost of three or four dollars, would have disposed of this soakage water, and made the road permanently firm and good.

Such attempts at roadmaking are like trying to make a field dry by closing up the spring holes. Water cannot be corked up in the ground as in a bottle; it will ooze out somewhere. A soil saturated with water is never firm, and the only way to insure a firm roadbed is *to keep it dry* by providing for the immediate discharge of all water which may fall upon it or sink into it. For the proper maintenance of any kind of road, there is nothing so important as that the foundation should be *firm* and *dry*. A firm, dry roadbed supports and drains the surface, keeps it firm, and hinders the formation of ruts and holes, and (what is perhaps of greater importance in a climate like ours) almost entirely prevents the destructive action of the frost known as "heaving."

If the subsoil be clay, or not naturally dry, it must be thoroughly underdrained. Deep side ditches will partially underdrain a narrow road, but deep ditches are dangerous. A single drain of three-inch tile laid down the centre of the road will generally be sufficient. The trench in which the tile is laid should be filled in with gravel, sand, small stones, or other loose material, since there is a danger of the clay becoming so compacted as to be almost impervious to water, and thus prevent the proper action of the drain. The cost of a rod of such a drain may be estimated as follows :

Tile	20 cts.
$\frac{1}{2}$ cubic yard gravel	40 cts.
Labor	15 cts.
Cost of drain per rod	75 cts.

It would soon pay for itself in the difference in the cost of maintenance, apart from any improvement in the condition of the road.

The advantages of easy grades are better appreciated than good drainage, and many of our roads are well graded, though very few are properly drained.

The work of grading has been rendered much more difficult by the bad system of road location already referred to, and much time and money has been spent in grading which might otherwise have gone towards draining and metalling.

GRAVEL AND MACADAM ROADS.

These roads should be graded and drained the same as Earth roads. In fact, the only difference between Earth, Gravel, and Macadam roads is in the character of the wearing surface.

For the economic maintenance of a metalled road, it is of great importance that the foundation be made firm and dry by thorough underdraining ; otherwise the metal will be continually sinking into the subsoil, and will require frequent renewal.

Gravel or Macadam roads dry more quickly than Earth roads, because they are harder, smoother, and yet more porous, and the water runs into the side ditches or filters to the underdrains more readily.

Broken stone is a harder and more unyielding material than gravel, especially when the latter is moist, so that the Macadam road is better for heavy traffic or wet weather. But if heavy loads in wet weather make ruts in a Gravel road, the ordinary traffic fills them in when the road is dry; whilst if ruts form in a Macadam road the subsequent traffic only makes them worse, and they must be filled in by day labor. This is an important consideration when comparing the cost of maintenance of a Gravel and a Macadam road.

A Macadam road is harder on the horses' feet than gravel, and unless in good repair is very rough and hard on vehicles, and much inferior to a well-conditioned Gravel road.

Macadam roads are more expensive in construction and maintenance than Gravel roads; but where there is heavy traffic, or much wet weather, and where ample provision will be made for thorough maintenance, they are more satisfactory in the end.

THE BEST ROAD FOR ONTARIO.

In determining the road best adapted to any locality, the decision will chiefly depend upon:

1. First cost.
2. Cost and convenience of maintenance.
3. Climate and soil.
4. Nature and amount of traffic.
5. Number of people directly benefited, and amongst whom the cost is to be distributed.
6. The average wealth of the community.

As a district increases in wealth and population, the traffic on the roads becomes heavier, requiring a more durable, if more expensive, road metal, while the cost of construction and maintenance becomes less burdensome, and is not such an important factor in the calculations. England is frequently cited as the country to be imitated in the matter of roads, and it is argued that because the English have good Macadam roads our roads should also be Macadamized. The weakness of this argument consists in the fact that it can easily be shown that the conditions upon which road construction depends are quite different in England from what they are in Ontario.

In the first place, the climate is very different. The English climate is wet, so wet that an English engineer, speaking of asphalt pavement, says, "Its one great fault of slipperiness, which requires it to be sanded every morning, is made up for by its being clean, healthy, and durable."

This shows the influence of the English climate on the roads better than any tables of rainfall or humidity.

In England there is little frost and no sleighing. In Ontario there are four winter months, during which the roads are frozen hard or covered with snow, and five summer months, so dry that even an earth road is in good condition. The traffic on the English roads is much heavier than in Ontario, and a material which would not stand their traffic might serve admirably for ours.

England is populous and wealthy, and the cost of construction and maintenance are of minor importance. In Ontario, where each farmer on one hundred acres is required to build and maintain about a quarter of a mile of road, the first cost and the cost of maintenance are very serious considerations.

In short, the English roads are in commission all the year, the climate is wet, the traffic is relatively heavy, and the country is populous and wealthy. Accordingly, the cost of construction and maintenance of a Macadam road would be counterbalanced by its adaptability to wet weather and heavy traffic. In Ontario the conditions are quite different. A wet-weather road is needed only three months in the year, the traffic is light, except in the vicinity of towns, and the population is so sparse that the cost of construction and maintenance may prove a heavy burden. In most cases the question will not be, "What is the best road that might be made?" but, "What is the best that may be made with the resources at our disposal?'

In a paper on "The Improvement of Country Roads," read before the Ontario Good Roads' Association, Mr. A. W. Campbell estimates the cost of converting our present earth roads into good, well-drained Macadam or gravel roads as follows—the material in each case being obtained within five miles :

	COST PER MILE
Gravel, width 8 ft., depth 9 in.	$1,334 00
Gravel with flake stone foundation, width 8 ft., depth 9 in	1,396 00
Broken stone, width 8 ft., depth 7 in	1,596 00

He does not refer to the cost of maintenance except in the following paragraph, which must be quoted full in order to be duly appreciated :

"To illustrate how the above figures would apply to township municipalities, I have prepared an estimate of the cost of improving 175 miles, being the road mileage at present maintained in the township of Yarmouth, adjoining the city of St. Thomas.

175 miles, cost $1,800 per mile	$315,000 00
Equal annual payments, 4 per cent., thirty years	$18,216 45
Maintenance $20 per mile	3,500 00
Total yearly payment	$21,716 45
Present maintenance, including statute labor at $1 per day	$ 9,000 00
30 years' actual extra rate	12,716 45
	$21,716 45

"Total acreage in township, 70,000.

"Assessed value, $2,700,000; per 100 acres, $3,850.

"Estimated actual value, $4,000,000.

"Extra rate required for annual payment, 4¾ mills.

"Estimated increase in value of property, 10 per cent., $400,000.

"In constructing 175 miles of stone road 50 per cent., or $157,500, would be expended for labor that could be performed by the ratepayers this would be equal to $225 per each 100 acres.

"The roads would cost $315,000, of which $157,500 would be spent in the township. The property would be increased in value $400,000. Taking these figures into consideration, the township would be benefited to the extent of $242,500 over and above the cost of construction of the roads."

The annual cost of maintenance of a first-class Macadam road at $20 per mile!!

With wages at $30 per month, it would require the appropriation for twelve miles of road to pay the wages of one man for eight months of the year, so that, according to *this* estimate, one man, working eight months in the year, would be expected to rake and roll the road, fill in ruts and holes, replace worn-out culverts and road metal, keep the drains and ditches clear, etc., etc., on twelve miles of road, and make the material as he went along.

Even with this estimate for maintenance, Mr. Campbell derives his large profit from a ten per cent. rise in the value of the land. Judge

Woods does better. He calculates how much cheaper it would be to *build* a gravel road than to *maintain* an earth road for fifty years.

The following is from his paper read before the Ontario Good Roads' Association :

" Here are some figures that I have put together, and you can judge of the result :

" Let us take the case of the statute labor account of John Smith, a ratepayer on a 200-acre farm, based on an assessment of 22 days, as may be found in one of the adjoining townships to this town, applied as at present on the ordinary earth road for 50 years, as against the borrowing of, say, $90,000, wherewith to make 45 miles of gravel road the first year, on the assessment of $1,000 for a 200-acre farm :

JOHN SMITH		DR.
To 22 days' work for 50 years	$ 1,100	
50 years' interest at 6 per cent	1,683	$ 2,783
Say there are 100 ratepayers, and they are, like John Smith, giving 22 days each, and you have at the end of 50 years, with only the ordinary earth road		278,300
Cost of 45 miles of gravelled roads made in 1889 by borrowing	90,000	
Interest at 6 per cent. for 50 years	135,000	225,000
Balance in favor of gravel road		$53,300

But if the assessment be low it may get as high as 30 days, as it has done. Let us put it in another way :

Statute labor as above	$278,300
Proportionate annual instalment on debentures for 90,000 upon the 100 owners of 200-acre farms at the rate of $1,000 at 6 per cent., $12.63, to give good gravelled roads in 1889, each $634.00	63,400
Balance in favor of debentures and instalment	$214,900

with the use of a good gravelled road in 1889.

"The London *Free Press* says of these figures: 'Judge Woods places the matter of bettering our roads in a clear, intelligent light, on purely mathematical and financial principles.'"

The arithmetic is correct so far as the writer has tested it. But would not even a good gravel road cost *something* for maintenance in fifty years? What would his good gravel road be like at the end of that time?

A false argument never benefits a good cause. Sooner or later, it will be exploded; and, if not, it does greater injury by giving rise to hopes which never can be realized. There is no doubt that good roads pay, and that municipalities cannot spend money more profitably than in judicious road improvement; but the advocates of good roads must depend upon more substantial arguments than the "purely mathematical and financial principles" quoted above.

With the exception of underdraining, which hinders the formation of ruts and holes, and the destruction of the road by frost, the benefits of road improvement are not to be found in a decreased cost of maintenance. These benefits are none the less real, but are derived from other sources, such as increased economy in the marketing of produce and the transaction of business, ability to do marketing at any season of the year, and thus take advantage of high prices, the increased value in farm property which always follows increased profits, and the pleasures and comforts which good roads provide.

The cost of maintenance is much more difficult to estimate than the cost of construction. There are so many contingencies, such as storms and floods, variation in traffic, and durability of material, that a close estimate on maintenance is nearly impossible. It will also depend upon whether the road is to be kept continually in as good condition as when first constructed, or to be allowed gradually to deteriorate and be renewed periodically. All estimates on maintenance should be based upon information showing what has actually been expended upon similar roads, whenever such information is obtainable.

In the county of York, some of the leading roads are Macadamized to a width of ten feet, and maintained by tolls. The following is an abstract of the expenditure on account of maintenance on two of these roads for the years specified:

EXPENDITURE ON MAINTENANCE.

Year.	Yonge Street (28½ miles).	Kingston Road (13 miles).
1884	$ 6,833	$ 3,473
1885	7,275	3,530
1886	9,710	3,442
1887	9,550	3,709
1888	7,546	3,994
1889	8,897	5,531
1890	16,170	4,295
1891	12,077	3,591
1893	11,994	5,816
	$90,052	$37,381
Average annual maintenance	$10,005	$4,153
Average per mile	$351	$319

The expenditure for 1892 was not obtained, but it is improbable that it would materially affect the result.

There is probably more traffic on Yonge Street and the Kingston Road than on other leading roads in Ontario, and the cost of maintenance on other roads would perhaps be less. But, in view of the above figures, the severity of our climate, and the cost of labor, $200 per annum seems to be a low estimate of the cost of maintaining a mile of Macadam road. If the original cost of construction were $16,000 per mile, and if half the cost of maintenance went towards renewals, this would provide for the renewal of the road metal once in sixteen years.

If all our roads were Macadamized to a width of eight feet, the owner of one hundred acres would be required to pay about $400 on construction and $50 per annum on maintenance. This is more than the average farmer can afford, and accordingly the roads would be ill-maintained and go to ruin, like many of the Macadam roads which now exist in parts of Ontario.

A gravel road does not require that constant attention and experienced labor which are so essential to the proper maintenance of a Macadam road. Being composed of a more yielding material, the ordinary traffic rolls it smooth, more especially if the heavy traffic is carried on wide tires; as it wears smoothly, and if it wears out it is because the gravel is pulverized or sinks into the soil. It never becomes rough and unendurable like a neglected Macadam road, and is generally better for driving on than the earth at the sides.

Mr. Campbell's estimate of the cost of construction of a gravel road is for a depth of nine inches. This depth would not be required, except where the traffic was heavy, as on a leading road near a town. One and a half cubic yards of gravel to the rod, spread to a width of eight feet and a depth of about four inches, is common practice, and is sufficient for most of our country roads.

If the road has not already been underdrained, this should be done before the gravel is applied; if not, the gravel will sink into the subsoil and be lost.

The following is an estimate of the cost of draining and gravelling a mile of road which has previously been ditched and graded:

3 in. tile drain, at 75 cents per rod	$165 00
330 cubic yards of gravel, at 80 cents per yard	264 00
Spreading and rolling gravel	15 00
Cost per mile for draining and gravelling	$424 00

The draining would not require renewal. Assuming that one-half the cost of maintenance went towards renewing the road metal, this road could be maintained and renewed once in fourteen years at an annual cost of about $40 per mile.

If all our roads were of this description, they would cost the owner of a hundred-acre farm about $100 on construction and $10 per year on maintenance. In this calculation it is assumed that our country roads are already graded and ditched, but not underdrained.

Ten days is the regular amount of statute labor on an assessment of $2,500. Reckoning this at $1 per day, and a hundred-acre farm as assessed at $2,500, the road just described could be maintained by the ordinary statute labor tax.

Such a road might not be so good as a carefully maintained Macadam road, or a deeper gravel road, and it is not recommended where the traffic would be heavy; but it is not beyond our resources, and if all our roads were no worse there would be little reason for the outcry for "better roads."

In the construction of a road there are three distinct operations: (1) grading and ditching; (2) underdraining; (3) metalling. The first two operations are permanent in their character, and when once properly performed do not require to be repeated, except at very long intervals, but the metalling is only temporary, and requires constant attention and frequent renewal. If all three operations cannot be performed at once, they should be carried out in the above order, for the underdraining cannot be made permanent until the grades are fixed, and any alterations in the underdrains disturbs the road metal. But draining should follow ditching and grading as soon as possible, in order that the latter may not be destroyed by frost and wet. Thus, in opening out a new road, the first thing necessary is that it should be properly graded and ditched, next that it should be thoroughly underdrained, and, lastly, that the surface be improved by the application of whatever road metal the nature of the traffic may require. Most Ontario roads have scarcely reached the first stage of construction—proper grading and ditching.

Returning to the kind of road which is both desirable and possible in Ontario, the roads may be divided into three classes :

1. Those on which there is heavy traffic.
2. " " " moderate "
3. " " " very little "

Roads of the first class are in the vicinity of large towns, and their mileage is comparatively small. The second class would include the roads connecting villages and lying along the favorite routes of travel, and whose maintenance is of general interest to the community. The third class would include the less frequented and purely local roads, many of which might, with advantage, be closed up altogether.

The first class of roads should be gravelled to a width of 8 or 12 feet, and a depth of 6 or 8 inches, or, if the traffic is very heavy, should be Macadamized. The second class should be light gravel roads, as described in this paper ; and the third class should be well drained and graded earth roads, with a light covering of sand or gravel where the soil is heavy clay.

These roads would not be too heavy a burden on the people, and could be well maintained. It must never be forgotten that the first requisite of a good road is proper maintenance, and an expensive road should never be constructed without the assurance that it will be properly maintained.

If an increase in the wealth or population of a district made a better road desirable, the only expense involved in the conversion of a third-class road into a second-class road, or a second class into a first class, would be the cost of applying the necessary road metal.

SYSTEM OF GOVERNMENT AND MAINTENANCE.

With few exceptions, the country roads of Ontario are maintained by the statute labor system, by which each resident or property owner in a township is required to contribute a number of days' labor (or in commutation thereof a money payment), proportionate to the assessed value of his property. The council of each township has authority to pass by-laws regulating the manner in which this work shall be performed, and appointing overseers or "pathmasters" to superintend its performance.

It has been the fashion to condemn the statute labor system as the chief cause of the unsatisfactory condition of our country roads. But the system has never been fairly tested. Apart from being badly administered, the statute labor has been required to do work for which it was never intended. It was intended for the maintenance of the roads, but it has been chiefly employed in works of construction—in grading and ditching. Can the system, then, be condemned if the little statute labor which was not diverted to works of construction has proved inadequate for the work of maintenance?

The following are the arguments most frequently made use of by those who condemn the statute labor system:

1. It places work requiring skill and superior intelligence under the direction of those who may possess neither.

2. All the work of roadmaking and repair is usually done in about one week, and during the very worst part of the season for such work—the end of July or the beginning of August.

3. Pathmasters undo year after year what their predecessors have done.

4. It is a lax system, and some may avoid performance.

5. It gives people the selfish idea that they are interested in roads only in their immediate vicinity.

6. Transient labor cannot be so systematically directed as can the labor under a contractor.

7. By it the roads are not only not properly made or repaired, but are absolutely being destroyed.

It does not require much ingenuity to expose the hollowness of arguments such as these.

The first three refer to the method of supervision of the road work, and not to the question at issue, which is: Would it be better to have the farmers pay their road taxes in money instead of in labor?

As to the fourth, no one can avoid performance if the overseer does his duty.

If the fifth has any weight, it can be easily overcome by making the road divisions larger.

The sixth may be valid, so far as *construction* is concerned, but would any one seriously consider letting out the *maintenance* of a road by contract? and the maintenance of the road is the proper province of the statute labor.

In view of what has already been accomplished under this system, the seventh needs no refutation.

It will be observed that all these arguments have reference to the manner in which the work is done, and are not valid until it has been shown that it is impossible or difficult to have the statute labor efficiently performed. Another objection seldom mentioned is that the statute labor system is applicable only where most of the work may be performed with horses and with laborers not specially skilled in roadmaking. Accordingly, the statute labor system, though applicable to a gravel or earth road, is inapplicable to a Macadam road, and in any case it should be supplemented by a few workmen constantly employed.

The fact that very few take advantage of the opportunity to commute their statute labor indicates that the majority of farmers find it more convenient to pay the tax in labor than in money. This is because the horses and men necessary for the work on a farm are not busily employed throughout the whole season, and it is an advantage to be able to avoid a money payment by letting them work upon the road at a time when they are not required in the fields.

If the farmers are to work upon the roads at all, it is simpler and more natural that each should do his share as statute labor than that they should pay taxes, part of which, after passing through several hands, would be paid back in the form of wages.

The statute labor system has this further advantage, that, when not particularly busy, the farmers often give some extra days' work when they would not vote money for the improvement of the roads.

The great drawback to this system is the manner in which it is administered. In the first place, the road divisions are too small. A few farmers, with an easy piece of road, have little to do; a few others, close beside them, on a difficult section, have more than they can properly perform. But the chief difficulty is with the "pathmasters"; there are too many of them, when so few of them know their work. The system of rotation of pathmasters, thus letting each man in the township have a try at the roads, is absurd.

The system is good in itself, but the manner in which it is ordinarily administered is indefensible.

How, then, can statute labor be properly administered? By dividing the Township into districts about five miles square, and placing each under the direction of an overseer appointed by the Council, and holding office during their pleasure. This overseer, who should be one of the most intelligent farmers in the community, would be expected to make himself familiar with all the most improved methods and machinery for road construction and maintenance, and would receive so much per day for each day employed upon the roads. He would have complete control of expenditure of the statute labor, and of the commutation or other road money to be expended in his district, and could order the work to be done in any part of the district. He should frequently examine and report upon the condition of the bridges, culverts, etc., and would have under him a small gang of laborers who would be constantly employed upon the roads. He would also have authority to appoint foremen, in case the statute labor could not all be performed under his personal supervision.

The township overseers should consult from time to time with the county or township engineer, and should carry on their work under his general direction. The leading roads which are of general benefit to the county should be placed under the immediate control of the county engineer, and maintained out of the general county rate. This should be done gradually at first, and, if found to work well, other roads could be added to those maintained in this manner.

The question rests with the Township and County Councils.

It would not be necessary to ask for fresh legislation, the present Assessment and Municipal Acts giving all necessary powers.

Under such a system the statute labor would be intelligently and efficiently performed; and, while giving satisfactory results, would be more economical and less burdensome to the farmers than the payment of road taxes in cash.

CONCLUSION.

In conclusion, there is no doubt of a well-founded demand for better roads, but the surest way to obtain them is not by a revolutionary change in the road system, but by improvements in the system which we have, according to the natural laws of growth and development.

And while it may not be advisable to imitate the English by building Macadam roads, and consequently abolishing statute labor, it *is* necessary to imitate them in "the three things to which the English roads owe their superiority," which are: "First, the stability of the foundations; second, the constant, and not spasmodic, attention bestowed on them; and last, but not least, the fact that they are under competent authorities in the county engineers and local overseers."

DISCUSSION

Mr. T. R. Deacon.—Mr. Duff's paper on "The Country Roads of Ontario" gives good evidence of a careful investigation of the subject, as well as experience in the matter. Good country roads are absolutely essential to the farming community to make the most out of the capital invested in their farms. I am well acquainted with parts of the country where the residents of one-half of a township must always sell their commodities at from 20 per cent. to 50 per cent. lower than those in the other half, because of difficulties in getting to market, when a good road might easily be built if the conservatism of the community could only be got over, and the benefits shown in such a logical way as to excite their slow powers of credibility.

With regard to Mr. Duff's remarks about the laying out of the original road allowances, I differ strongly from his opinion, as I do also from his suggestion about laying out farms to suit the configuration of the ground. I am surprised at Mr. Duff making such a suggestion, as I know he has had experience in laying out new townships. Who would undertake in a heavily timbered country to lay out land in such a way that when the land was cleared and drained it would be seen to have been laid out in the best possible way? Much better, in my opinion, to lay out the land, as is now done, in rectangular blocks, and then make the roads in the best place for them, only making them conform to the original survey lines when it is practicable to do so, and at other times as nearly so as is *economically* practicable. I think with Mr. Duff that in many parts of Ontario the "pathmaster" system cannot be got over for some time yet, but that that system can be much improved in the newer parts of the province, in the manner suggested by Mr. Duff. In the older and wealthier portions of the province, I believe better results could be obtained from the expenditure of the same amount of labor skilfully directed by a competent road builder than in the desultory and haphazard way in which my experience leads me to believe the "road work" is commonly done.

Mr. J. R. Peddar.—There is some question as to whether it is advisable to follow Mr. Duff's specification, where he says, "The trench in which the tile is laid should be filled in with gravel, sand, small stones, or other loose material," etc.

Filling the trench in this manner will cause the water collecting in the trench to quickly run in the joints of the tiles from tops and sides, which will, in most cases, carry sand with it.

Does not a tile drain act in the same manner as the crest of a dam in regard to taking off the water?

In wet land the water rises and rises until it finally oozes out on the surface of the ground, whereas, if a tile drain be put in, the water will soak the ground until it reaches the bottom of the tile, when it is carried away, and the height of the water in that part of the ground is kept as low as the tile drain.

If this be so, is it not, then, as some authors contend, advisable to pack clay in the trench immediately above the tile? thus preventing sand being carried in the top of the tile, which will eventually block the drain.

I might also add, in regard to materials for good roads, that the best road in this part of the township is formed of 8″ or 10″ of the refuse of brick kilns, brick bats, etc., covered to a depth of 9″ with the cinders which are raked out from beneath stationary boilers. This road, although continually subject to the passing of wagons loaded with bricks, does not wear out, nor allow ruts to form as quickly as the gravel roads. The cost of the materials is nothing, as, if the pathmaster did not make use of them, the proprietors would be at an expense in hauling them to a suitable dumping ground. The cinders from two 75 horse power boilers are more than ample for keeping a half mile of road in repair.

Although the above materials can hardly be quoted as general materials for road construction, there are a great many places where they can be had, where they are not made use of, but are allowed to be wasted.

Mr. W. F. Van Buskirk.—I am by no means satisfied that there is a demand in Ontario for better roads. There are any number of complaints, both on account of roads and taxes, but I cannot discover anything that could be called a demand for improvement among the great mass of the people in the western district. The average citizen thinks that we have as good roads as possible for the money expended, and cannot see that anything is to be gained by investing more money. Any one wishing ocular demonstration of this has only to look at the average driveway from roadway to barn.

I am, therefore, of opinion that improvement will come through the action of the Provincial or Dominion Government. This is in accordance with the experience of Great Britain, France, Germany, etc. The Provincial and Dominion authorities will, however, take no action in regard to improvement until such time as the public are sufficiently educated in the matter to submit to interference with the existing state of affairs. Some time ago, I wrote to *The Canadian Engineering News*, suggesting that the government undertake the instruction of the public in roadmaking in a similar way to that in which butter and cheesemaking is being taught.

I am convinced that one mile or so of properly made earth road in each county or township will do more to educate the public than all the papers we may write in the next few generations.

This method has been lately adopted by the State of Massachusetts, where three miles of Macadam road are being built in each county.

The assumption that "our country roads are already graded and ditched" is entirely unwarranted. At the present moment, I cannot think of a single piece of road that does not require a large amount of work in grading and ditching to put it in a fit condition for either macadamizing or gravelling. The failure to recognize this is the great cause of waste under the present system. Gravel and stone are piled on roads year after year, and as quickly sink into the wet ground beneath.

In order to form a good foundation for a road, the ground must be made and kept dry to a depth of at least four feet, and must be thoroughly compacted by rolling with a roller weighing not less than five tons, all hollows being filled as they appear under the roller. Steam rollers weighing about ten tons will do better and cheaper work than horse rollers in consolidating the earth of newly-graded roads, but are a little heavy for rolling gravel.

Tile drains are not always necessary, as in many cases the side ditches (not gutters), if made of sufficient depth, will dry out the subgrade in addition to carrying the storm water.

Drainage requires much more skill than is generally supposed. The ordinary farmer cannot lay tile drains properly, the said farmer to the contrary notwithstanding. I strongly object to filling in trenches over tile with gravel, sods, or any loose material whatever. Water enters tiles through joints from sides by gentle flow or movement horizontally along top of water table when drains are working properly; and any loose material above tiles permits water to flow direct from surface and fill up drains with sand, etc. My practice is to lay tiles in a trench cut with a drainage scoop to the exact shape of the lower half of tile, and to fill the trench with earth or clay well rammed over pipes, so as to leave the ground in, as nearly as possible, the same condition as before cutting the trench.

I agree with Mr. Duff, to some extent, in the belief that the statute labor system can be made to work, but am of opinion that the gangs must be in charge of permanently employed, skilled foremen who would be directly responsible to engineers trained in roadmaking. The ordinary township engineer is generally a surveyor, knowing no more about scientific roadmaking than the ordinary pathmaster.

Mr. Duff seems to have lost sight of the fact that good roads have a cash value to all persons using them, and that they will, undoubtedly, increase the value of farm lands, so that it would be possible to spend more money upon them than is done at present.

I am of opinion that the only question that should be considered in determining the nature of road to build in any locality is No. 4 on Mr. Duff's list, "Nature and amount of traffic." All other considerations must be subordinate to this in order to keep the road good.

No doubt properly-constructed earth roads, with a little gravel on the surface, will answer in most cases; but wherever the traffic is heavy, as upon main roads between town and through townships, the roads should be macadamized, and kept up in the most approved manner.

Mr. Campbell's idea of cheap, and therefore nasty, Macadam roads, maintained at a cost of $20 per mile, is rather amusing, but does not merit consideration among engineers.

I do not expect much improvement under present management and methods, and am of opinion that any change short of thorough reorganization will only cast discredit upon the promoters and the movement for reform.

That untrained troops require the most highly-trained and efficient officers is a well-known principle among military men, and applies equally well to men employed upon engineering works.

Mr. James McDougall.—The subject of road improvement is one of deep interest to me.

I think the writer is on the right tack in advocating good gravel or earth roads which can be more easily maintained than Macadam roads. Still it is not going far enough to keep up an agitation in favor of good roads. There are portions of the province, such as parts of the counties of Essex, Kent, and some others, where gravel is very scarce and the cost of laying it down on the roads almost prohibitive, owing to long haul. Such conditions should also be discussed. It is most important that the roads be well maintained. In this connection Mr. Duff very properly laid great stress on the influence of thorough underdraining. I might mention a case which has occurred in my own practice. I had been superintending the cutting down of a hill on the Kingston Road, where the ground showed indications of springs. I had two tile drains laid down the road about eight feet apart. These thoroughly drained the hill, which is hard and firm even in the wettest weather, and the Macadam over the drains does not require nearly so much repair and renewal as on other undrained parts of the road. From my experience with municipal councils, I feel safe in saying that it would take a great deal of argument to persuade the farmers to raise money by debentures for road improvement. The railway bonuses proved such a heavy burden that they are not likely soon to repeat the experiment. In the county of York, some of the townships have been making good roads. In Vaughan township, where the soil is very heavy clay, many of the roads, especially the trunk roads, are well gravelled, a policy inaugurated some years ago by a newly-elected reeve. Previous to that time about $2,500 had been spent on the roads annually. The first year of his term of office the expenditure was raised to $3,000, and afterwards this amount was raised, till it has reached an annual expenditure of $6,000, and during last year but $5,000 was expended. The policy was so acceptable to the people that the reeve, after several elections by large majorities, was returned by acclamation until his policy had been fully carried out, when he retired, after securing the wardenship of the county. The townships of Markham and Georgina had also done extensive work on gravelling roads, Georgina especially being mentioned, owing to the excellent supply of gravel in the township. I think that great encouragement and impetus could be given to road building and improvement by a judicious system of bonusing, as in the case of public schools, where government grants have immensely improved the material conditions and efficiency of such institutions. With this end in view, I would suggest that the roads of the province should be considered under three heads :

(1) Roads of provincial importance in which traffic is through more than one county. Such roads as, for instance, Yonge Street, Dundas Street, the Kingston Road, the Governor's Road, the Toronto and Sydenham Roads, and others throughout the province.

(2) Those of county importance, where the traffic crossed more than one township ; as, for instance, in the county of York, the Weston and Vaughan Roads on the west, and the Markham Road on the east.

(3) Those of only local importance within the townships.

While the management and expenditure of all moneys should be vested in the local authorities, roads of provincial or county importance should receive provincial or county aid, to be granted only on condition that the road be kept at a certain fixed standard of excellence.

These roads would require to be inspected periodically by a provincial and county inspector respectively, on whose recommendations the grants would be made, as in the case of schools obtaining government grants. The local authorities, in order to obtain these grants, would see that the roads were efficiently maintained, and a spirit of emulation would be inaugurated, even should the grants be comparatively small.

I am in accord with a great deal that Mr. Duff had said in reference to statute labor. Its proper rôle is the maintenance of roads, and not their construction. In Vaughan it is used to great advantage in this way, teams being employed to work the road machine to level down ruts and round up the crown of the roads after the spring rains and traffic has put them out of shape.

Mr. S. M. Johnson.—We are greatly indebted to Mr. Duff for his clearly stated views upon this important subject. We are all interested in the advancement of this movement for better roads, but we must recognize that there is nothing which in the end retards a needed reform more than overestimating the advantages to be derived, or stating the increased cost at too low a figure, and thereby causing disappointment and a reaction against the movement.

The tables regarding the cost of the macadamized roads of the county of York are very interesting, although their cost does not compare favorably with the English roads. It must, however, be remembered that if the system were to be extended the cost per mile would be lowered, as these roads are situated where the greatest traffic, and, therefore, the greatest wear, occurs. I would like to ask Mr. Duff at what season of the year the metal is placed upon the York roads. We all know that upon our average road under the statute labor system the material (when any is added) is laid on in the early summer, and just at the season when the roads are naturally at their best, which, instead of improving the roads, diverts the traffic to the side.

In my experience I have only seen one attempt to obviate this, and in that case the gravel was placed upon the road just as the frost left the ground in the spring, and when the roads are generally at their worst. The result was that the traffic soon had the new material compact, and in the summer a good road resulted, and there is no doubt, had the road been first scraped, the advantage would have been still greater. I am of the opinion that could a system be devised whereby gravel could be placed upon the roads after scraping in the spring and fall a great advance would be made.

The thorough drainage of the roadbed is an important part of the construction of any road, and especially is this the case in Canada, where the frost, by its "heaving" action, does so much damage, this being greatly aggravated by the presence of water. The English roads are underdrained in many places, but these drains are not intended to carry off the surface water, but to cut off all water from the subsoil, their aim being to make the road surface impervious, and thus shed all surface water towards the side ditches.

Mr. Duff.—I do not think that my remarks on the location of roads would bear the interpretation placed upon them by Mr. Deacon; it certainly was not intended that they should. The basis of all land subdivision should be rectangular, and I never thought of the surveyor's lines being run other than as they are. It was not proposed that the original surveyor should divide the township into irregular blocks, but that the settler should have more freedom in purchasing any portion of a lot or of two adjoining lots, so that the lands which naturally lay together should belong to the same farm. What I did object to was the practice of blindly "following the lines run by the surveyors" in those cases where better roads and more compact farms would have been obtained by deviating from them. I am pleased to note that Mr. Deacon's views on this subject are very similar to my own.

I am indebted to Messrs. Van Buskirk and Peddar for pointing out the mistake which occurs in the description of the filling in of a tile drain. The sentence should have read, "*The upper part* of the trench in which the tile is laid should be filled in with gravel," etc. When tile are laid they should be covered with three or four inches of clay, well rammed in about the tile; this will prevent any loose material from working into the joints. When clay is not available for this purpose, sods, hay, or straw, or similar materials, are sometimes used, but these are only necessary in the case of quicksand.

My theory of the action of a tile drain is somewhat different from theirs. The pores of the soil form so many channels through which water may flow. But water will not flow except down grade or under a pressure head higher than its level, and if the flow is obstructed the grade must be steeper or the pressure greater. In every case of underdraining there will be a surface separating the soil from which the water is drawn off from that which is below the influence of the drain. This surface may be called the *water table.* In sandy, porous soils, through which water flows freely, it will be practically horizontal; but in clays, where the flow is impeded and is not along horizontal lines, the water table is inclined. The inclination for ordinary heavy clay is about one vertical to ten horizontal;

so that the water table to a drain three feet deep would intersect the surface at about thirty feet on either side. If the clay is made more porous or the flow of water facilitated in any other way, the water table will be more horizontal and the influence of the drains extended.

One way of accomplishing this is to fill the upper part of the trench over the tile with gravel, thus making a large trench to which the water will flow, and then filter through the few inches of clay to the drain underneath.

The object of underdraining is not merely to carry off the water which oozes into the subsoil under pressure from a distant head. No matter how hard and smooth the surface may be, the rain water will not be all shed into the side gutters, some will sink into the subsoil. An important function of the underdrain is to carry this water off rapidly, and prevent it from rendering the roadbed soft and yielding, or subject to the influence of frost. This beneficial influence of the underdrain is more noticeable in earth and gravel roads, where a larger proportion of the rain water is retained by loose earth, ruts, etc., until absorbed into the soil.

I am much pleased to observe the unanimity of opinion with regard to the necessity for underdraining in order to secure a firm, dry roadbed, which is the most important requisite in a good road. Yet this is the very condition which in practice is most neglected, perhaps because the destruction occasioned by a wet subsoil goes on gradually and unseen. If the government adopts Mr. Van Buskirk's suggestion, and gives public instruction in roadmaking, the first lesson to be taught is the necessity of a firm subsoil, and that if the subsoil is not naturally very dry it must be underdrained.

It is said that the assumption "that our country roads are already graded and ditched" is entirely unwarranted. If the writer had considered that they *were* properly graded and ditched, it would have been stated as a *fact*, and not as an *assumption* made merely for the purpose of facilitating the calculation. In counties of York and Simcoe (with which I am most familiar) a great many roads are well graded and ditched, whilst on the others the amount of grading and ditching done is so variable that it would be difficult to make a general estimate of the cost of completing the work. It was simply to avoid making this estimate that I assumed that the roads were ditched and graded, and I do not consider such an assumption misleading or unwarranted.

I concur in Mr. Van Buskirk's opinion of Mr. Campbell's cheap Macadam roads. Such erroneous ideas do no harm amongst engineers, but where they are widely disseminated amongst the farmers (who are, after all, the men who decide what kind of roads we are to have) then every engineer is in duty bound to expose the error, especially in such a case as the present, where Mr. Campbell's position as City Engineer of St. Thomas may give to his opinions a prestige they might not otherwise possess.

In the case of Judge Wood's "figures," I regret having taken up space with such misleading and ridiculous "calculations."

Although the nature and amount of traffic is the most important consideration in determining the kind of road which *should be* built, and the essential condition of the road to be thoroughly maintained, yet necessity knows no law, and the vital question for us in Ontario is: *What is the best road that we are able to maintain?*

One of the objects I had in preparing this paper was to call our road reformers down from quixotic discussions on the theoretically best road, and induce them to grapple with the conditions which actually do exist in Ontario. Would a man spend his time planning how to erect a castle, when he has only an axe and a few nails with which to build a cabin?

Scientific roadmaking is not necessarily the work of a surveyor, and many a good surveyor may know nothing of making roads. But the education of a surveyor is such that he can easily learn the science of roadmaking, and should he be township engineer, and it be made a part of his duty to superintend the roads, he could make himself proficient, or, if not, could be dismissed as incompetent.

In answer to Mr. Johnson's question, I would state that the new metal is placed on the York roads in the spring and fall. The difference between the cost of maintaining these roads and English Macadam roads is no doubt due in some measure to the cause mentioned by Mr. Johnson. Other causes which may be mentioned are the severity of our winter frosts, the difference in the price of labor, the character of the soil, which is nearly all heavy clay, and the fact that they are imperfectly underdrained.

I think very favorably of Mr. McDougall's plan of provincial and county subsidies, provided that they are expended, as he suggests, by the local authorities. This might be combined with the writer's suggestion, that the township councils divide the township into about four divisions, and place the roads in each under the supervision of an intelligent farmer, who would make a special study of roadmaking, and personally superintend the expenditure of all road money and statute labor in his division. This I believe to be the best practical solution of the road question in Ontario.

AERIAL MECHANICAL FLIGHT

C. H. MITCHELL, B.A.SC.

The following paper is, for the most part, a compilation of prevailing theories and ideas advanced by different writers, together with the results of observations and experiments which have up to the present been made in this new field of science. It is well recognized that until recently the subject of mechanical flight has been the object of considerable ridicule, but the fact that the scientific world is rapidly turning its attention to aerodynamical research warrants us in making haste to acquaint ourselves with the progress in this direction.

I wish it to be distinctly understood that I am not a disciple of any particular method or theory of flight, and that I have interested myself in the subject for no other purpose than to become familiar with the underlying scientific principles.

I have attached this title to the following paper chiefly for the purpose of discriminating against what has up the present been known as aeronautics, but which is now referred to as aerostation. Within the past five years there has come forcibly before the eyes of the world a new branch of aeronautics—that now known scientifically as aviation, and which shares with the former the chances of aerial navigation. Heretofore "aerostation" has won all the fame which has been conferred on aerial invention, and the disciples of that branch of the subject have looked down with a commiserating eye from their lofty vantage on their struggling brethren of the aviation family. A well-known writer very tersely puts the discrimination in this way: "There were two roads to possible success—the one broad, beautiful, smooth, and bordered with flowers, but, after all, leading to no result—it was that of aerostation, of balloons, lighter than air; the other way was contrariwise, a rough, narrow, rugged path, bristling with difficulties, but still leading to something—it was that of aviation, of rapid transit by machines heavier than the air."

I do not propose at this point to discuss the question of balloons *vs.* mechanical flight (that will come in further on), but I desire to point out that this paper will deal exclusively with the newer branch, its history, its aims, designs, and possibilities. Owing to the fact that the subject is in its merest infancy, that no literature of a responsible nature of a date previous to 1881 is obtainable, and that the greater part of it is in periodical form of a very recent date, particularly since the aerial congress at Chicago in 1893, the compilation of a comprehensive paper is somewhat unsatisfactory unless all information is thoroughly trustworthy.

I consider that this new branch of science which has so suddenly and forcibly thrust itself upon us is one which we as engineers should at once make ourselves sufficiently acquainted with, so as to be prepared for its actual development, which is assuredly not far distant. With this view, I have taken time by the forelock, and have endeavored to give to the members of the Engineering Society the benefit of my reading and observation in the subject during the past year.

If there is one haunting predominant conception more than another which to-day infests the mind's fancy, it is that we may possibly before long be soaring the air, partners with the feathery tribe which have since the beginning held universal sway in the realms of Æolus. Unhappily, some of our fellow-men have fallen dire victims to the conception, and, if they have *lived* long enough in the possession of it, have been looked at askance with pitying contempt, and dubbed "cranks," perhaps too persistently. Now, however, this dream of the enterprising inventive genius is drawing near to its realization; he no longer stands before the finger of ridicule, no longer is he classed with the seekers after the elixir of life and perpetual motion; the past few years have been more lenient, and his innings has come.

Perhaps the cause of the ridicule which has been so ludicrously hurled at the disciples of the "flying machine" during the past may be summed up in a few words. Heretofore our attention has been called to mechanical devices for the most part designed and built by mechanics, without a thorough scientific basis—in fact, with no other recommendation than that "they *ought* to fly." Of course the results could have been foretold. Now, however, we find scientific men of the very highest reputation delving into the previously existing data, making new deductions, performing all kinds of preliminary experiments and tests, but proceeding in the most cautious and logical manner, content with "making haste slowly"; their fondest hopes being that in a few years a machine that will raise itself off the ground may be constructed. The scientific world has acquired confidence in these men, and has ere this proceeded to offer assistance in a very tangible manner, so that now we find scientific societies, clubs, and single experimenters all combined in a grand race for the goal not far distant.

Much of the experimentation so far concluded may be said to be based upon the work of the early physicists, notably Newton, Gay Lussac, and Hutton, though the results of these men have been greatly modified —in fact, sometimes have they been found entirely at variance with nature. As before intimated, these results were not made use of for any aeronautical purposes, all the attention being bestowed on the balloon, with the result that no particularly successful method of aerial navigation was forthcoming. I do not mean to say that no advantage was gained, for the balloon has been most valuable in all scientific directions, and by its means we have discovered some of the idiosyncrasies of the upper air currents, a thorough knowledge of which, by the way, is an absolute necessity for successful navigation. But the balloon has so far demonstrated one important thing, and that is that for rapid and complete aerial flight for all purposes we must look not to the gas bag—lighter than the air—but to the fully-equipped heavy machine, with inherent capabilities, as it were, of sustaining and propelling itself in all conditions of wind and weather. It is needless to point out how this has been brought about, for the very circumstances of ballooning are against it as a means of navigation. Balloons are costly, clumsy, easily damaged, and with difficulty repaired; they are dependent, for the most part, on fair weather, perfectly helpless in a wind storm, and, above all, are slow. The great war balloon "La France" accomplished only fourteen miles per hour. There are balloons now under construction by the same experimenters (the French Government) which are to attain twenty-five miles per hour. This will be, if successful, a truly great accomplishment, but when we remember that such balloon trips are limited necessarily to a few hours, and that the maintenance commercially is enormous, while there is only a thin piece of silk between success and complete collapse, we are in this age of business enterprise slow to consider it advantageous.

It seems almost absurd for men of our scientific age to look toward the gas bag as a means of aerial suspension, for what is there in nature to warrant such? What parallel is there? All birds are much heavier than their enclosing fluid, and motion is accomplished by the purely mechanical effort of their muscles and organic members. We have heretofore considered the birds as beyond our powers of imitation, or else have entirely ignored them. We have almost with ridiculous contempt passed over the everyday principles underlying the kite, the boomerang, or the skater on thin ice. We have discovered the uselessness of the gas bag, and have sought to replace it by some mechanical device of wondrous intricacy, a galaxy of propellers and screws, *a la* Jules Verne, forgetful of the fact that there are scores of birds which for hours together soar in the air almost without dynamic effort, using only the wind currents, and that in the simple kite of our juvenile days is the secret of their movement. These things are now fully recognized by the scientific world, and the current of research has accordingly veered around in the new direction, so that, in place of intricate mechanical creations, we find the much-talked-of "aeroplane."

The result of all this is that we have now, out of a multitude of designs and principles, hit upon what, as far as we know, is going to lead to something substantial—a single line of experiment only, toward which all energies are being bent.

The basis of these investigations may be divided into three distinct parts, which it will be necessary to consider in the abstract before we touch upon the principles of the flying machine. This division may be made as follows:—(1) The flight of birds; (2) observations on the principles of the kite and other similar contrivances; (3) abstract experiments in the "laboratory." These constitute our data, and their value as such will be in proportion to their reliability. Having discussed these divisions, it is the province of this paper to consider the generally accepted theories of the ideal "flying machine." It will then be in order to review what has actually been done in the experimental world with reference to aerial navigation, which means a résumé of the different machines now constructed and on trial.

Bird flight, after years of close study by naturalists and physicists, still remains very much an enigma. It may appear easily, or with difficulty, accounted for, according as one looks at it. It is one of the few unsolved everyday problems which have been so prolific of discussion during the past years in the scientific world. Perhaps the most insurmountable difficulty which presents itself for pursuing investigation in this direction is that of the inaccessibility for experiment and observation. Could we spend our time side by side with the birds, we might soon discover their secret. Those to whom we owe our present knowledge in this subject have obtained their information with great difficulty, and, even then, it is, for the most part, very incomplete, and does not furnish us with any real precise data. Were it possible to domesticate the birds we are most interested in, and place them under close scrutiny in the laboratory, the task would be simpler, perhaps, but the results not as valuable.

Before considering the flying process, let us examine into the anatomy of the bird with reference to flying. For our purposes, the bird consists of three parts, the body, the wings, and the tail. Theoretically considered, the two wings and the tail form the supporting members, though the function of the latter, in this regard, is very much restricted. The centre of gravity is, of course, situate within the body of the bird, though it can be shifted by means of the movement of the wings. The body proper and the tail serve, generally, to obtain steadiness and equilibrium; in some birds, having a deep breast bone, the body acts like the keel of a ship. The wing consists, essentially, of three parts, having two joints, by means of which the whole can be contracted or extended. The peculiar joint system, and the strong muscles, permit of movement of the wing in almost any direction with very great rapidity. The general structure of the wing is a marvellously exquisite contrivance, combining strength, flexibility, and lightness. With the quills hollow and tapering, and the web composed of overlapping feather vanes, closely clinging and fitting into each other, the whole comprises an exceedingly light aeroplane, impermeable to air under certain conditions. The quill of the feather, as we all know, is nearer to the forward edge of the plane surface, which edge is turned downwards, and the forward feather underlies the next one back. From this it is seen that the wing, on an up stroke, can be made to permit the free passage of air *downwards*, while, on a down stroke, it would be impermeable. The wing bones are all situated on the forward edge of the wing plane, so that a flapping motion partakes, partially, of a rotation of the plane about this forward axis, and the ends of the strong wing feathers (primaries) flex upwards on the down stroke.

The wing and its action is, to us, the most important. It has two distinct functions: that of a propeller, and that of a sustaining aeroplane, though the relative use of each varies exceedingly in different species. Insects and small birds use their wings almost entirely as propellers, beating the air and flapping, sometimes, with great rapidity. Large birds, having wing surface of great expanse, resort, to a very great extent, to soaring and gliding by means of their wings as aeroplanes. There are, essentially, two kinds of wings: the one, long, and the other, short. It can be easily understood that a bird with long and wide wings is well prepared for soaring, an adaptability which increases with mass; also, that the bird with long and narrow wings can fly in great winds, that short and narrow wings can attain great speed, while short and wide wings produce but ordinary flight. By these considerations, we may enunciate the law that velocity is in inverse ratio to wing surface. Though we speak of birds' wings as aeroplanes, it is only to a few of the smaller birds and the insects that such can be really applied, for most wings are concave on the underside, a fact that, though known, has not been greatly recognized by investigators until recently.

In Plate 2 are shown three positions of the wings of a bird, to illustrate the mode of changing the centre of gravity ; no explanation is necessary.

The tail of the bird serves, to some degree, three functions—to sustain, to direct, and to preserve equilibrium, though it is not a necessity to flight, for many birds have little tail, and all birds, when deprived of their tails, can manage to fly. The size of the tail has no apparent effect on the flying qualities, though very large tails denote feeble flight. The tail is most valuable in acting as a rudder, and swift birds utilize a very powerful tail in changing direction quickly, so that the law might be stated, that the aptitude for changing direction of flight is in direct proportion to the size and power of the tail. It may also be used to shift the centre of gravity forward or backward, and, in some cases, to serve as a third supporting plane.

Curious explanations of bird flght have been presented by some investigators, in which they attribute much of the unexplainable to the fact that the bones of the bird are porous and contain spaces presumably filled with rarefied air. Such, certainly exist, but the explanation is considered very weak, for, by actual experiment, it is found that the specific gravity of the bird without its feathers is about unity, the same as that of man, mammals, and fishes. Even a water bird, if deprived of its feathers, will sink. It has been urged that there is some property in the feather covering which assists flight. This, apparently, can be true in only one sense, viz., that it forms an elastic cushion, frictionless in the air, displacing more of that fluid, and, hence, lowering the specific gravity, though to a small degree only. Strangely, however, it is found that a bird, when stripped of his body feathers (thus leaving him his wings and tail intact), will still be able to fly with apparent ease, though, perhaps, awkwardly at first.

Hence, then, if we are to attribute the flying powers of the bird to its actual organism, we must look to other quarters. We see that the bird is much heavier than the air, for it immediately falls to the ground when shot. We know that birds can fly under nearly all conditions of weather, that they can fly with body feathers stripped, with tail cut, and with wings clipped, also that they can still fly if artificial wings are substituted. What, then, can we do but consider the bird as a machine, a highly organized mechanical creation, sustaining itself through the reactions produced by muscular effort, "not as a balloon floating in the air, but as a stone glancing along the water, or a skater gliding over thin ice"?

Our study of birds now takes two courses as regards aviation, the one that of flapping, and the other that of soaring flight. Flapping flight, as far as the bird is concerned, is easily explained, and requires but brief attention. The following description is that presented by Mouillard in "L'Empire de l'Air":—Presuming that the bird is on the ground and ready to fly, he is crouching to spring upwards, his wings hanging loosely, the position, then, of the three parts of the wing is such as to offer little resistance to an upward thrust, the feathers being "edge on." The bird makes the jump, and, at the same time, the upstroke, the whole wing being contracted and close in towards the body, so as to present the least possible surface, and yet quickly and easily execute the movement. Then comes the down stroke. The wing is fully extended and stiff, all feathers completely overlapping, and forming a surface concave on the underside. The "down stroke" is downwards and backwards, and this accomplishes not only an upward, but a forward movement. The effect is easily seen by reference to Figure 1, Plate 1. The wing is then again contracted, moved forward and upward, then extended, and ready for another down beat. Flapping flight is used by certain birds continually, while other birds alternate it with soaring, and others use it only on occasions such as when rising quickly from the ground, on a calm day, or when surprised. The angle of rising motion is seldom greater than 45°, and a vertical rise is rarely seen, being at best a most difficult manœuvre. This method of flight apparently requires great power and endurance on the part of the bird, and it is generally found that all the small and light active birds use it.

Soaring or sailing flight, though simpler in appearance perhaps, is much more difficult of explanation, and, in fact, is not yet explained to the satisfaction of the investigator. In it there appears to be the very secret of aerial flight we are so desirous of discovering, but even now, though it yet remains a mystery, we are assured that by copying the soaring birds as far as we are able we are pursuing the most natural and logical course toward the desired end. We are all now pretty well aware that there are many birds which sail on the air without apparent muscular propulsion, utilizing some subtle inherent force either of the air or themselves. The principal of these are to be found in the tropics, and are, in

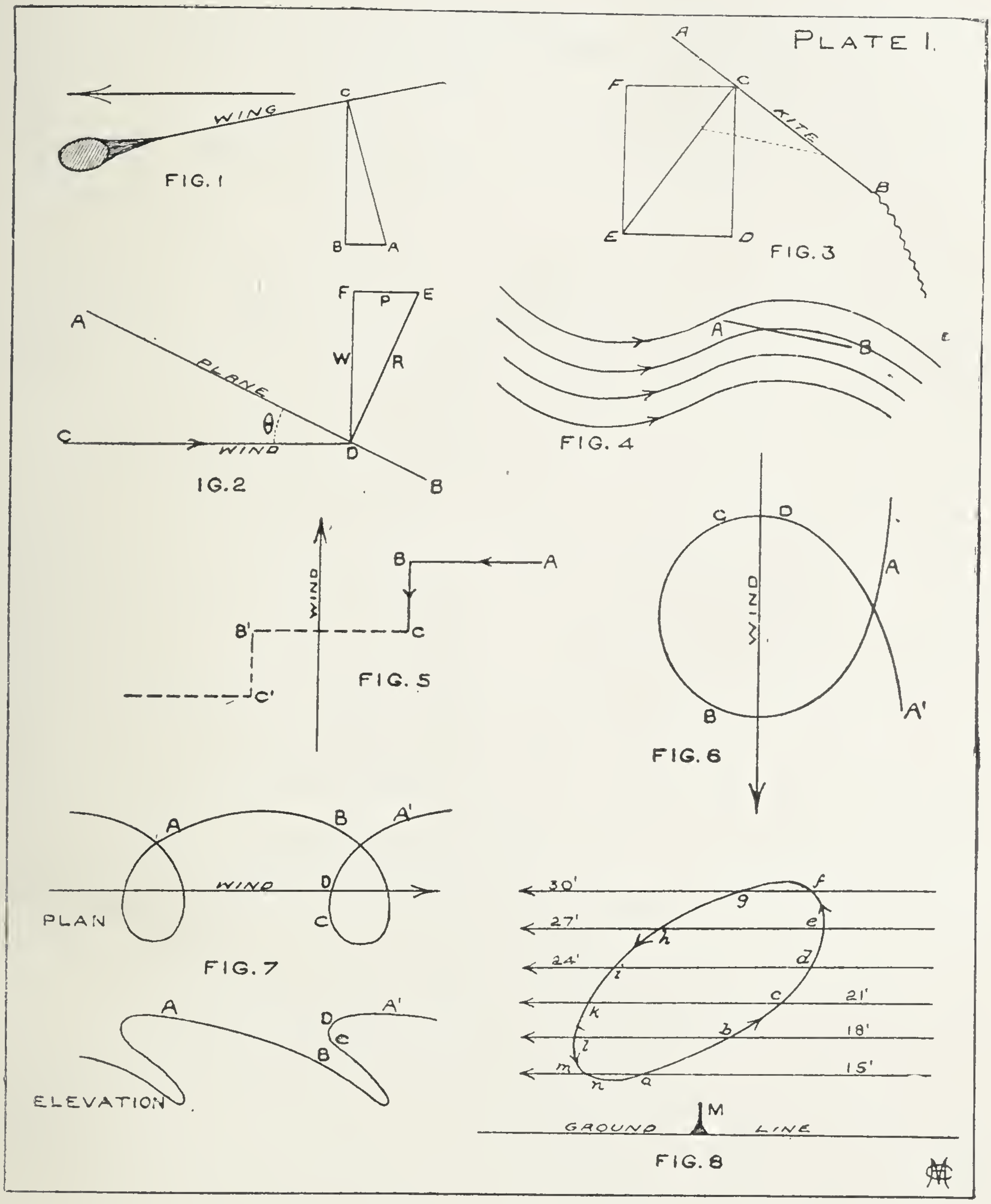


PLATE I.

FIG. 1

IG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

general, large birds, while a few smaller species inhabit more northern latitudes. The gull, petrel, albatross, hawk, kestrel falcon, the pelican, kite, buzzard, and vulture, are the representative members of the soaring class.

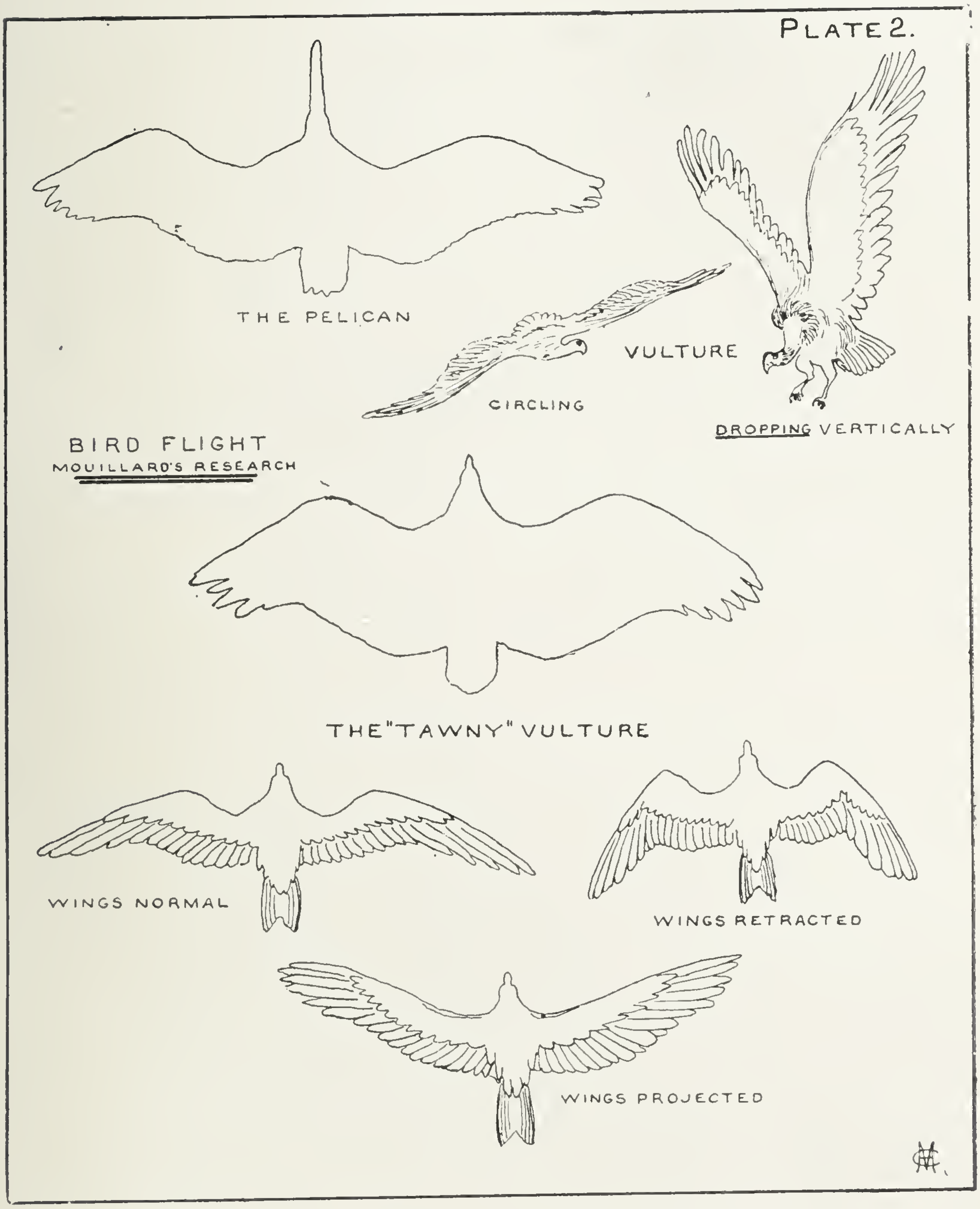
The discussion of soaring requires a thorough knowledge of the behavior of the air currents passing over the earth's surface, and this is just where we are at a loss, for we know comparatively little of anemometry. Perhaps a thorough exposé, as it were, of the antics of the winds, particularly with reference to local disturbance, would solve the question of soaring flight.

No better way of explaining soaring flight can be presented than by describing that indulged in by a representative bird, and for different reasons we will take the great tawny vulture (*Gyps fulvus*) as our teacher. I will again refer largely to Mouillard, as he has perhaps been the greatest student of this bird. This vulture, as is well known, is at home in the east, and has been watched most closely at Cairo, Egypt. As a flyer he is most successful, and when we couple with that fact another one, namely, that he is the laziest bird created, we must conclude that he sustains himself with the least expenditure of force, and hence flies with the utmost science. His weight is very great, and his wings large and powerful, two facts which at once mean momentum and sustaining power. He weighs, probably, sixteen pounds, and spreads his wings eight feet or more, with perhaps eleven square feet within his contour—a truly magnificent aeroplane. The bird himself has a forbidding and repulsive look, but his bright eye and powerful movement invite us to a closer inspection. He is certainly lazy, for he will rest in his rocky eyrie during the gray dawn and far into the forenoon, until the land breeze springs up, when he flaps his wings and limbers up, yawns, as it were, and with a jump and three or four beats of his wings he launches forth for his day's work. He descends, perhaps, thirty yards on rigid wings, gaining momentum, and is soon in full soaring flight, with wings extended and tipped slightly backwards. Now comes the interesting series of manœuvres; he commences a series of circlings, of a helicoidal nature, and we discover him climbing up into the heavens, without a single wing beat; higher and higher he goes, his wings always rigidly extended, changing their position only when he turns abruptly. When he has gained an elevation from which he can survey the surrounding country for his meal, he proceeds to pursue his usual pastime, that of waiting. He glides in great circles, now against the breeze, now with it, he makes long, but graceful descents, and rises again in some mysterious manner to his former altitude. He may remain aloft in this way for hours, gently sailing on the breeze, when suddenly he descries from afar the meal for which he is in search, and he commences a long, steady, majestic descent, swift, but dignified, which soon lands him at his prey. During the whole morning's work he has scarcely flapped his wings once. True, there has been a breeze, but almost imperceptible. "When we watch a martin flashing through space, we think of high speed mechanism; when it is a snipe or a partridge which flies off, we are reminded of the action of a released spring; a gull suggests perpetual motion, but the view of the great vulture in sailing flight inspires at once the desire for imitation: it is a dirigible parachute which man may hope to reproduce."

Let us turn our attention to other similar instances of bird flight. A typical case is related by M. Bretonnière as he saw it at Constantine, Algeria. Storks commonly performed a series of circular orbits, similar to that shown in Figure 7, Plate 1. From A to B the bird, with a certain momentum, descended in the direction of the wind, then he glided across and upward against the wind to C, crossed it at D, thence to A, whence he commenced a long but slight descent, repeating the operation as before. The series of movements is of course made without flapping. The same gentleman finds that a bird can hold itself head on to the wind and remain practically in the same position in space. He finds that certain birds will precipitate themselves from a height of, say, a hundred feet in order to raise themselves, *against* the wind, to a greater altitude. He also tells us of instances of birds sailing downwards in a gentle wind which, when arriving at a certain exposed place, encountered a very strong wind from a side direction; they immediately headed against the wind and rose twenty or thirty yards very rapidly, whence they commenced circling.

Mr. E. C. Huffaker has made a number of valuable observations on vultures in the mountains of Tennessee. He finds that in a wind of thirty miles per hour the vulture cannot make any soaring headway against it, but resorts to a system of vertical tacking. The bird can, by exposing the underside of his wings properly to a strong wind, rise vertically, though being drifted backward. By sailing *across* the wind a very swift flight may be attained horizontally, in which the bird, however, heads so as to make a slight angle with the wind, also the swift flight may be stopped by facing the wind. The same writer tells of the following instance of a buzzard soaring about fifty feet above a level, open field, when, by reference to neighboring high trees, not even a slight breeze was noticeable. The flight was elliptical and of a velocity of twenty-five feet per second, requiring about five seconds to complete its orbit. It made some twenty

PLATE 2.



BIRD FLIGHT
MOUILLARD'S RESEARCH

revolutions in a horizontal plane, so that in about a minute and a half it progressed some five hundred feet, having maintained its original elevation and velocity, and not flapped its wings. He says that in the above case of horizontal soaring, a slight increase of velocity could be detected as the bird passed the vertices of the ellipse. This is most noticeable in the common mode of flight. "Instead of moving in horizontal circles, the bird consumes such energy as it may possess by gliding upwards. Having lost its velocity it hangs for a moment almost motionless, turns backward, sweeps suddenly downward like a wheel with the outer wing greatly elevated; then with a single powerful stroke brings the wings and body into a horizontal position and speeds away with a velocity due to a fall of twice as many feet as it has taken."

Mr. Lancaster, the well-known naturalist, finds that frigate birds are able to go at the rate of one hundred miles per hour on fixed wings, and also that they can live for a week on the wing. Professor Le Conteu gives us numerous examples of albatross flight, notably that of following a boat against the wind. The bird skims the surface behind the boat, but of course falls behind rapidly; he then rises quickly *against* the wind, wheels and swoops downward *with* the wind, until he has gained a great velocity, after which he turns again toward the wind, and, skimming the water, overtakes the boat.

I have given these brief examples of bird flight for the sake of showing concisely what evolutions birds are capable of accomplishing. To explain them and to apply the principle to man flight is another matter, and a discussion of such will be now in order.

Before proceeding with that, however, it will be of advantage to look briefly into the matter of wind currents as regards bird flight, and also into general consideration of flight of birds. Wind usually blows in a generally horizontal direction, and may vary in uniformity, that is, come in gusts or squalls, or may change in velocity. It may be blown into undulating currents either vertically or horizontally, as is seen from smoke ascension. It is also affirmed on good authority that the air is stratified, as it were, with reference to velocity. That is to say that the farther up we go the greater velocity there is. That such is so on occasions we know from simple experience, and we recognize the fact that the earth's surface, be it ever so level, must exert a retarding influence on the wind. In this regard we have yet to discover that on what we call a calm day there is a stiff "sailing" breeze up where the birds manœuvre. Unevenness of the earth's surface exerts, of course, a tremendous effect upon the air currents. The intensity of wind on the brow of a hill may be much more than on its side, because there may be a strong upward pressure along the sidehill, the result of the upward diverted current; this would create an upward sustaining breeze at the brow. There are many other cases also where an upward current may be encountered. Downward currents are also frequently formed. The observations on thistledown, smoke, snowflakes, and sand show the varying moods of our "enclosing envelope."

For every pound weight of bird pressing downwards there must be an equivalent upward pressure to insure suspension alone, without propulsion. This upward pressure can be produced in only two ways, either by some natural pressure of previously existing air currents, or by an effort expended by the bird in giving a downward motion to air previously at rest. The former acts only on occasions, as we know when there is an ascending current of air. Generally speaking, then, the bird must set up a downward current by some means at every point of his route, and the greater volume of air he displaces, and the quicker he does it, the better suspension he obtains, and, if he is moving horizontally, the greater his velocity; that is to say, the more air he will pass *over* and force downward in a given time. The soaring bird's wing is curved concave on the underside, as previously stated, which teaches us a very important thing. We all know that the impulse derived by a surface on which a moving fluid is impinging is proportional to the change of direction of motion caused by such surface. This is the principle on which the blades of a screw propeller, a turbine, or a windmill are constructed. Consider a plane (Figure 2, Plate 1). Suppose a wind current is acting on it obliquely. A particle of air striking the forward edge at A would be deflected, and would pass downwards along the plane to B. The effect is the same for every point on the surface, and when the particle once strikes its work is done, as it passes off the plane without doing work. Some particles of the air current lower down may, perhaps, never reach the plane to do work. If, however, the surface is slightly curved, with the greatest curvature at the forward end, the particle of air striking at the point A has, during its passage to B, its direction continually changed, and it consequently does work till it passes off at B. In this, then, the curved surface has the advantage over the plane, and this is the reason that birds were created with concave wings. Looking again to Figure 2, Plate 1, let CD be a horizontal current of air impinging in the plane AB at D. The direction of the force created by such will be normal to the plane, viz., DE. Let DF be the direction and intensity of the lifting effort; then EF will represent the horizontal motion or "drift." This is the general diagram for the aeroplane under air pressure.

The full significance of this is not quickly realized, particularly when the angle ADC is slight. As an illustration, hold a stiff fan outside the window of a railway car moving at, say, thirty miles per hour. It is very surprising how great the uplift is when the angle is small. In the figure let ADC be θ, R the normal pressure, W the uplift, and P the resistance to horizontal motion. Then we have $W=R \cos \theta$, and $P=R \sin \theta$. Then $P=W \tan \theta$. But horse power exerted would equal VP when V is the velocity. So that with V in feet per second we have $HP = \frac{VW \tan \theta}{550}$ If, therefore, we could discover the weight, velocity, and angle of wings of a sailing bird, we could compute the horse power he is using. It is to be noticed that the extent of surface does not enter, though it is of considerable importance, depending altogether upon weight. If it is small, great velocity and angle are required for sustentation; if large, it becomes cumbersome and heavy. In either case power is consumed. With a given sustaining surface and angle there is some velocity of wind which would just overcome the force of gravity and air resistance, and the bird would then sail horizontally against the breeze. Should the wind drop, or should the bird enter a sheltered space, or increase the angle of wings, he will descend by force of gravity. If the wind increases, or the bird increase his velocity by any means, or decrease the angle of wings, he will rise (against the wind). We learn all these points from the foregoing figure.

Rather than outline the different theories in explanation of soaring flight, I will discuss several of them very briefly, though, as yet, no one has satisfactorily explained the problem. It is practically admitted by all, despite certain trustworthy observations, that soaring cannot be done in still air. The very laws of nature forbid such. All considerations eliminate the air resistance of the bird, and admit the soaring process to be accomplished by some adjustment of the wings in conjunction with a natural knowledge of the wind currents and their several effects. (It has been pointed out that the noise made by buzzards, when flying, may be caused by a continuous flapping of their strong pen feathers at the tips of the wings, a motion not capable of detection.)

There are numbers of problems for solution. How can a soaring bird sail with the wind at a faster rate? How can he rise above his starting point against a wind? How can he travel at a certain rate against a strong wind? and many others. All can be answered by the solution of one problem, which may be stated as, " How can a bird sail indefinitely in a horizontal breeze, retaining his altitude, and using his wings only as aeroplanes?" Such sailing, usually, takes the form of circling, whether progress is made or not.

M. Bretonnière points out how limited are the chances of sailing flight in a truly horizontal path, and shows that such can be accomplished under only two conditions: the one, that of ascending currents, and the other, that of squalls or gusts of wind; the advantage of the latter will be explained later. Generally, then, this writer shows that the bird transforms the ordinary horizontal currents into "relative squalls" by two artifices, viz., the zigzag path and the spiral. The former may be explained in its simplest form by reference to Figure 5, Plate 1. We will suppose the bird to be at the point A, and, for convenience, have no initial velocity. Let it perform a downward glide in the direction AB *across* the wind, thus acquiring a velocity V at the expense of an altitude h. Suppose now, neglecting resistance, shock, and other causes of loss, the bird turns to the *left against* the wind (BC) and proceeds to transform its kinetic energy into work again. Suppose the wind is blowing in the direction indicated, at a velocity v', then, when the bird turns against the wind, he has a velocity of $v+v'$. Now, the altitude $h=\frac{v^2}{2g}$, and a kinetic energy of $\frac{1}{2}mv^2$ is required to procure it. When the bird is passing from B to C his kinetic energy would be $\frac{1}{2}m(v+v')^2$, and the corresponding altitude obtained $H=\frac{(v+v')^2}{2g}$, subtracting:—$H-h=\frac{(v+v')^2}{2g}-\frac{v^2}{2g}=\frac{2vv'+v'^2}{2g}$, which is the additional height which may, under these circumstances, be obtained by the bird. With the spiral, the same reasoning applies. In Figure 6, Plate 1, the bird plunges downward from A to B across the wind, and from B to C up against it (having his wings inclined above the horizon, of course), while from C to D he may rise somewhat further, across the wind, by a proper adjustment of his wings, then a gentle downward glide at will towards A′ to resume the same operation. The last part of the manœuvre covers a great distance if the bird is travelling, but is short if he is ascending. Should the bird desire to travel against the wind, an angle of wing can be found which will carry him forward and downward at the most economical rate, when he can rise at pleasure to any elevation, though with loss of distance. Thus Bretonnière emphasizes the motion downward *across* the wind and *upward* against it.

Mr. William Kress, of Vienna, Austria, deduces a solution depending on the increasing velocity of air currents as we ascend. Without going into his elaborate explanation, I will present a copy of his figures and diagram, showing how a bird, without muscular effort, can perform a vertical orbit and gain in speed. Let Figure 8, Plate 1, represent an orbit traced in air currents of varying intensity, as shown. Let M be a reference point on the earth. Let the bird attain a velocity of 45 feet per second with respect to the air. The following table will explain the process of the flight. The argument is that the bird loses no relative speed when working against the air, but gains when flying with it, due to gravity.

Velocities.	a	b	c	d	e	f	g	h	i	k	l	m	n
Speed of wind	15	18	21	24	27	30	30	27	24	21	18	15	15
Absolute speed of bird	30	27	24	21	18	15	72	72	72	72	72	72	39
Relative speed of bird	45	45	45	45	45	45	42	45	48	51	54	57	54

Thus the bird has completed the orbit and increased its speed by nine feet per second. The preceding result, is perfectly possible on the hypothesis that the air currents are varying, a fact which is already partially proven by experiment.

Professor Langley has suggested a theory of soaring which, though faulty, may have some value. It depends on the law of wind-pulsation, which he has investigated. There is no doubt that wind currents are more or less undulating, which can be seen by the ducking of a kite at periodical times, of smoke, etc. By reference to Figure 4, Plate 1, in which the arrows show the direction of the currents, and AB the aeroplane at a small angle to the horizon, a sustaining and upward motion is given to the latter in the position shown, while additional speed can be attained by a downward glide in the intervals between "the gusts." A general tendency, then, would be upwards, a result which could also be obtained if moving against the wind, though not as rapidly.

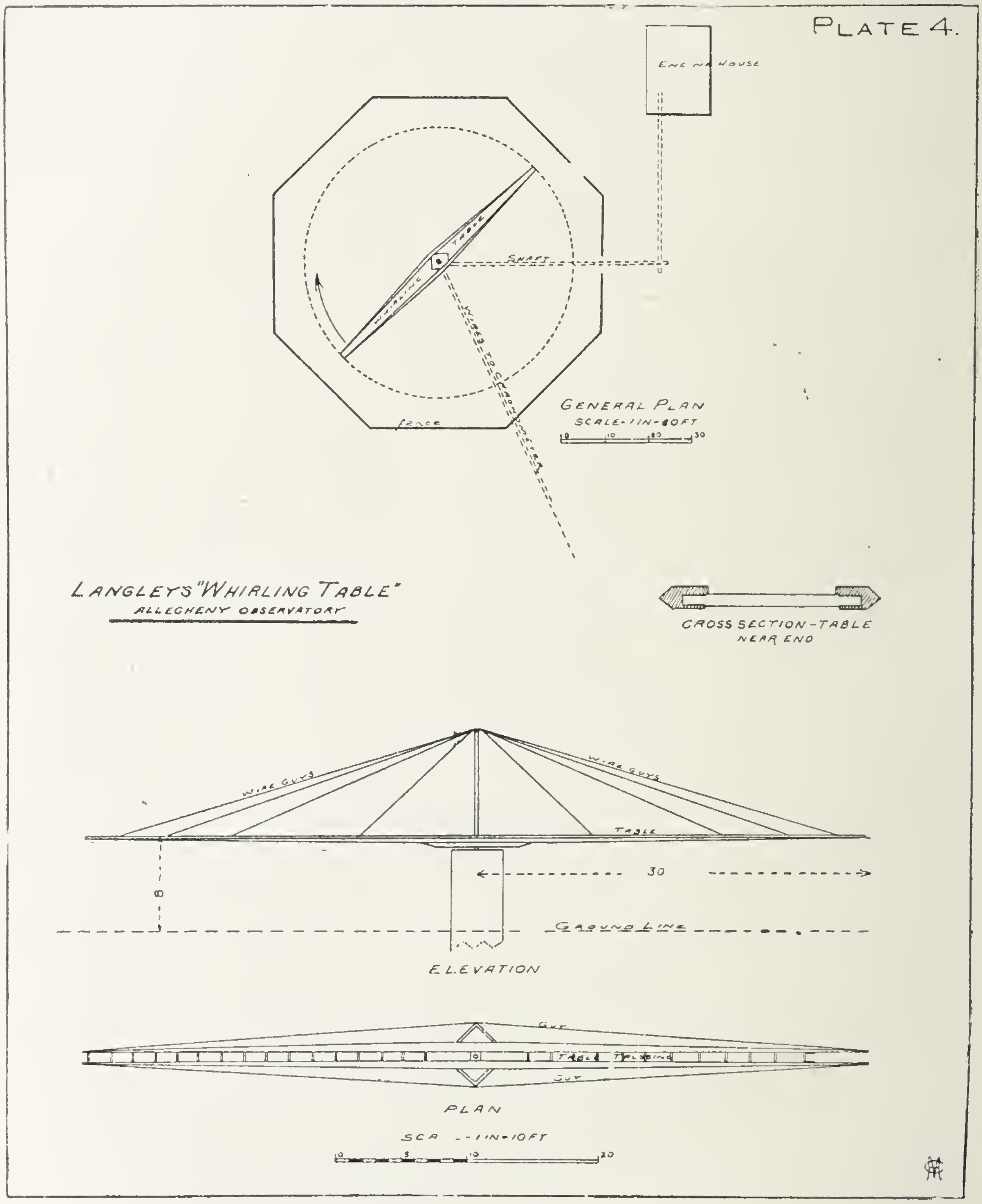
A consideration of any of these solutions would serve to explain the phenomena of soaring flight. But how, we ask, does all this lead to the solution of man flight? Simply in this: supposing we were thoroughly acquainted with the laws of aerial currents, and possessed the knowledge of turning them to our use, we could by adjusting to ourselves a sufficient aeroplane and a mechanical device for individual propulsion be enabled to sustain ourselves in the air under similar conditions. From research which has already been made, it seems as if man would be unable to sustain himself in the air by means of an aeroplane pure and simple, but that some means of propulsion must be utilized. By reference to the table on Plate 3, this will be recognized. The results are taken from Mouillard, and show figures on sixteen well-known birds. The original figures were in the gram meter system. The last column, deduced from the preceding ones, is the one in which we are immediately interested. It shows the relative surface required to sustain the weight of a man and light apparatus, in respect to the different birds. It will be seen that the wild duck furnishes the example of the lowest, but we cannot look to that bird for our model. The vulture is the heaviest bird given, and presents the most promising model in every respect, showing some 135 square feet of aeroplane required for man. We will see later on how this agrees with actual experiment. All the other birds present too great relative surface for practical use.

We will leave the subject of bird flight at this point and look briefly into the next division of our data—that of the kite. We have all flown kites, and know something of their behavior. They are of many shapes and sizes, and may be built of almost any material, and flown in many ways, but the principle of sustentation is the same. When held by a single string, the surface is perpendicular to it, which shows that the thrust of the air is normal to the kite. We remember, too, that there is always a particular point at which the string must be tied which gives the best flying results, and this point is *above* the centre of gravity. This shows roughly that the centre of pressure is not coincident with the centre of gravity of an aeroplane. A similar diagram of forces may be constructed for the flying kite as for the bird's wing. Thus in Figure 3, Plate 1, let AB be the kite, and C the centre of pressure where the string is attached. Construct the parallelogram of forces where CF represents the drift and CD the lift. If to the lift we add the weight of kite tail and string, we get the total carrying power; and if from the drift we subtract the drag of the tail, we get the power required to hold the kite, or otherwise to *propel* it through the air. This is the ordinary kite with which we are familiar. We have frequently heard of types of kites which are flown in the East, notably by the Chinese, Malays, and Javanese. These are tailless kites, and are flown in the most sluggish breezes, in fact, almost in a calm. I had the opportunity of seeing one in the Javanese village at the World's Fair in 1893. A type of such kites is shown in Figure 2, Plate 8, and was constructed by Mr. W. A. Eddy, of Bayonne, N.J. He has flown it in an exceedingly slow breeze and can fly it in a calm by walking at the rate of a couple of miles an hour. He

PLATE 3.

COMMON NAME.	WEIGHT OF BIRD. POUNDS.	SURFACE WITHIN CONTOUR. SQ. FEET	SPREAD OF WINGS. (A) FEET.	MEAN WIDTH OF WING (B) FEET.	PROPORTION. $\frac{A}{B}$	ONE LB. OF BIRD'S WEIGHT SUSTAINED BY SQ. FEET.	ONE SQUARE FOOT SUSTAINS POUNDS.	RELATIVE SURFACE REQUIRED TO SUSTAIN 200 LBS. SQ. FEET.
WATER FOWL....	1.309	1.031	2.28	0.518	4.40:1	0.787	1.270	157.4
GOSHAWK........	0.638	1.109	2.36	0.525	4.48:1	1.738	0.575	347.6
NIGHT HAWK....	0.136	0.434	1.70	0.262	6.36:1	3.191	0.313	739.2
GULL............	0.510	1.175	3.10	0.427	7.27:1	2.304	0.434	460.8
PETREL..........	1.540	1.283	4.10	0.410	10.0 01	0.833	1.200	166.6
WILD DUCK	2.035	0.901	2.36	0.360	6.54:1	0.442	2.26	88.4
WILD GOOSE.....	4.444	2.627	4.49	0.623	7.26:1	0.591	1.692	118.2
PELICAN.........	14.575	10.750	9.19	1.279	7.17:1	0.737	1.355	147.4
SCREECH OWL....	0.671	1.519	3.08	0.541	5.69:1	2.264	0.442	452.8
NIGHT HERON ...	1.353	1.949	3.41	0.656	5.20:1	1.441	0.694	288.2
STORK...........	4.708	6.620	6.82	0.984	6.93:1	1.406	0.711	281.2
KESTREL FALCON.	0.398	0.990	2.43	0.410	5.92:1	2.480	0.402	496.0
KITE............	1.408	3.090	4.36	0.721	6.04:1	2.195	0.456	439.0
FISH HAWK......	2.794	3.542	5.08	0.787	6.45:1	1.270	0.789	254.0
TAWNY VULTURE.	16.500	11.250	8.24	1.460	5.64:1	0.682	1.466	136.4
NUBIAN VULTURE	17.934	11.980	8.75	1.509	5.76:1	0.667	1.497	133.4

PLATE 4.


LANGLEY'S "WHIRLING TABLE"
ALLEGHENY OBSERVATORY

has found that just previous to a reverse of the breeze, the kite partakes of a rocking motion from side to side, as if beating the air like a bird. When the wind ceases the tension on the string is released, and it hangs downward ; the kite then slowly descends in a slanting direction, but when the wind comes up from another quarter the descent ceases, the kite catches the wind, backs away, and ascends again.

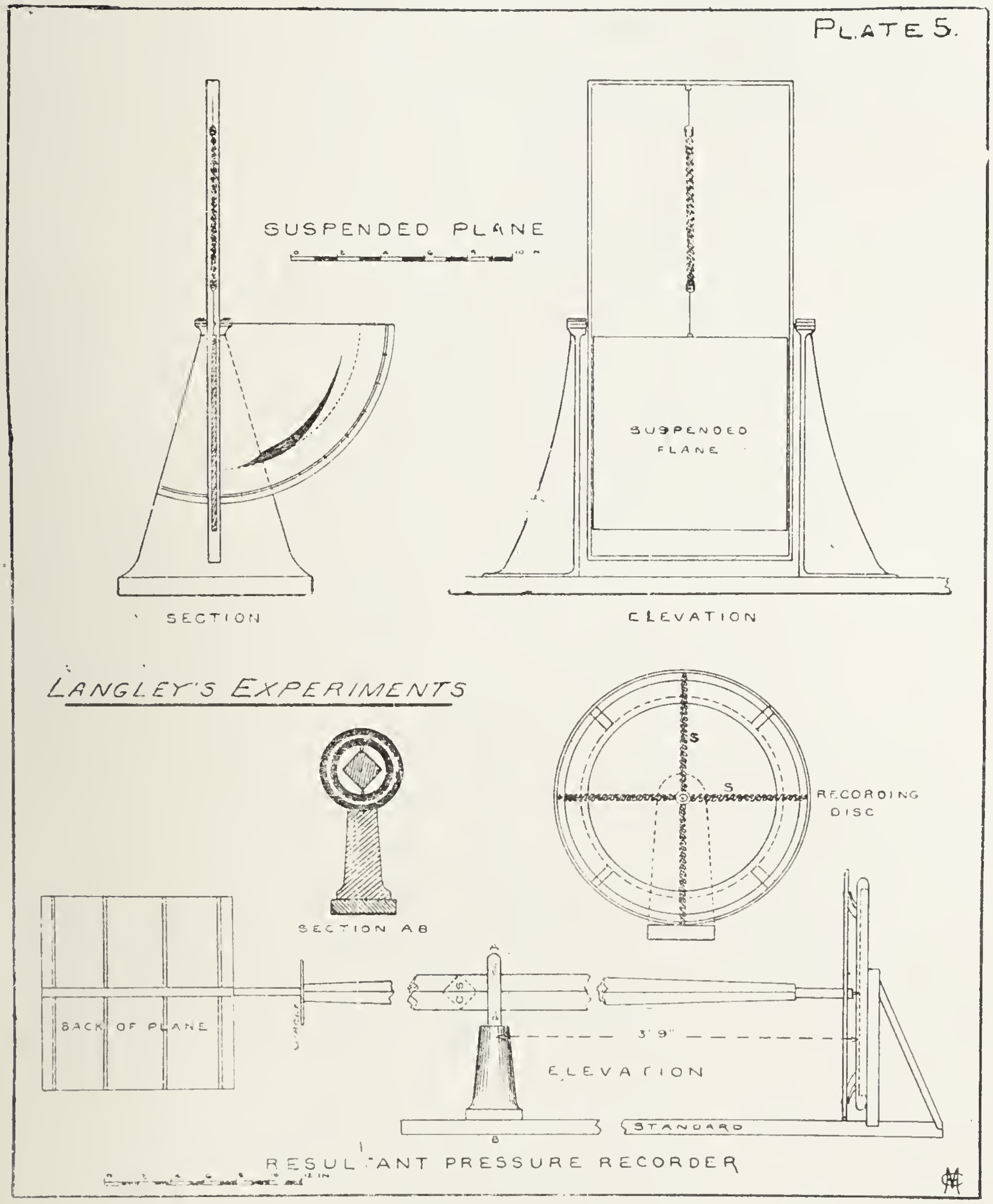
No little attention has been directed to the singular kites constructed by Mr. Lawrence Hargrave, of Australia. A type of these is shown in Figure 1, Plate 8. The principle involved depends on two well-known facts: "The necessary surface for supporting heavy weights may be composed of parallel strips, superposed, with an interval between them" (see Wenham and Langley); and "two planes, separated by an interval in the direction of motion, are more stable when conjoined." The construction partakes the form of a cellular pigeon-hole box on the underside of the compartments of which the wind acts. The angle at which they float is very small, and as a consequence the kite may take up a position almost in the zenith. It is found that a kite with surfaces concave on the underside pulls about twice as strongly on the string as a similar one with plane surfaces.

Investigations "in the laboratory" form one very reliable source of information in regard to the sustaining powers of the aeroplane. Prof. S. P. Langley, of the Smithsonian Institute, Washington, has without doubt furnished us with the most valuable information on this subject. He made his experiments at Alleghany Observatory, and I will briefly review a few of these for the purpose of showing important laws governing the pressure of the air on moving planes. His elementary apparatus consisted of a "whirling table," as shown in Plate 4. This table consisted of a very light wooden trussed structure sixty feet long, and pivoted on a shaft at the centre. By suitable gearing this vertical shaft and the table could be made to revolve at any speed, power being supplied by a small steam engine. One end of the table was arranged for attaching certain apparatus for testing purposes, the balance of each arm being retained. By an electric circuit and a chronometer attachment, the complete behavior of the table could be recorded. The arms revolved at a height of eight feet from the ground, and the whole was protected from winds by a high board fence. The outer end of the table could be made to travel at any rate up to 100 miles per hour, and the motion was at such a radius that it could be considered practically linear.

His first experiments were made with the suspended plane, as shown in Plate 5. This consisted of a plane suspended in a frame, and free to slide up or down under the balanced impulse of a spring. The whole frame was free to revolve on a horizontal axis, the lower part, having the plane, being heavier, however. A graduated circle was attached together with a pencil recorder. The whole instrument was placed on the end of the arm of the whirling table, and the table revolved, the plane and frame being exposed to the direction of motion. The pressure of air caused the lower part of the frame to swing backwards, while the plane travelling forward at an angle on to new air released the tension of the spring, and consequently rose in the frame, the pencil recording the amount of rise. In the figure the records of the pencil are shown shaded. The significance of this experiment is easily seen.

The next experiment in logical order was that of the resultant pressure recorder. When a plane is advancing on the air at an angle above the horizon, the resultant pressure varies in intensity and direction according to that angle. This apparatus was constructed to investigate this. An arm, shown in Plate 5, was hung at the centre in gimbal joints in a support and standard, which was attached to the end of the table. The arm was about seven feet and a half long, and at one end carried a pencil and at the other (outer) a plane of any convenient size which might be inclined to the horizon at any angle, a circle being attached for reading such. The arm was nicely balanced, and the pencil fitted through a collar which was attached to four calibrated springs (SS), and played on a paper disc placed in a support. When the apparatus was set in motion on the table, the plane being placed at any desired angle, the pencil recorded on the paper not only the intensity of the pressure (as reduced from the calibration of the four springs), but the direction or "excursion of the trace" in reference to co-ordination. This "excursion" could be made in *any* direction with equal facility. In this way a law of the resultant pressure could be deduced. Newton's law in this instance made the pressure on a plane moving in a fluid vary as the square of the sine of the angle between the plane and the line of motion. Mr. Langley's researches have shown that this is quite erroneous, and, though his apparatus was constructed more for an approximation to the quantitative pressures than for precision, the discrepancy is sufficiently great to entirely change the complexion of the previous law. As an instance, for an angle of 10° the theoretical vertical pressure would be $\sin^2 10° \cos 10° = 0.030$ of the pressure on a *normal* plane moving with the same velocity. According to these experiments under similar conditions, it is 0.30 of the same pressure, or ten times greater. Rather than give any tables of Langley's results, I have plotted a curve representing in general the rate of variation

PLATE 5.



LANGLEY'S EXPERIMENTS

RESULTANT PRESSURE RECORDER

of the pressure; that is, the ratio of the total normal pressure P on an nclined plane to the pressure P_n on a normal plane at the same velocity. In the diagram, Figure 1, Plate 7, the abscissæ are the angles of inclination to the horizon, and the ordinates the ratio or percentage of the pressures ($P \div P_n$). I have also plotted a curve showing the Newtonian law within the same limits. The inferences from this diagram will hardly need explanation. The practical experiments show that the lifting effort increases much faster with the angle than was hitherto supposed, a fact which is surprising and most important.

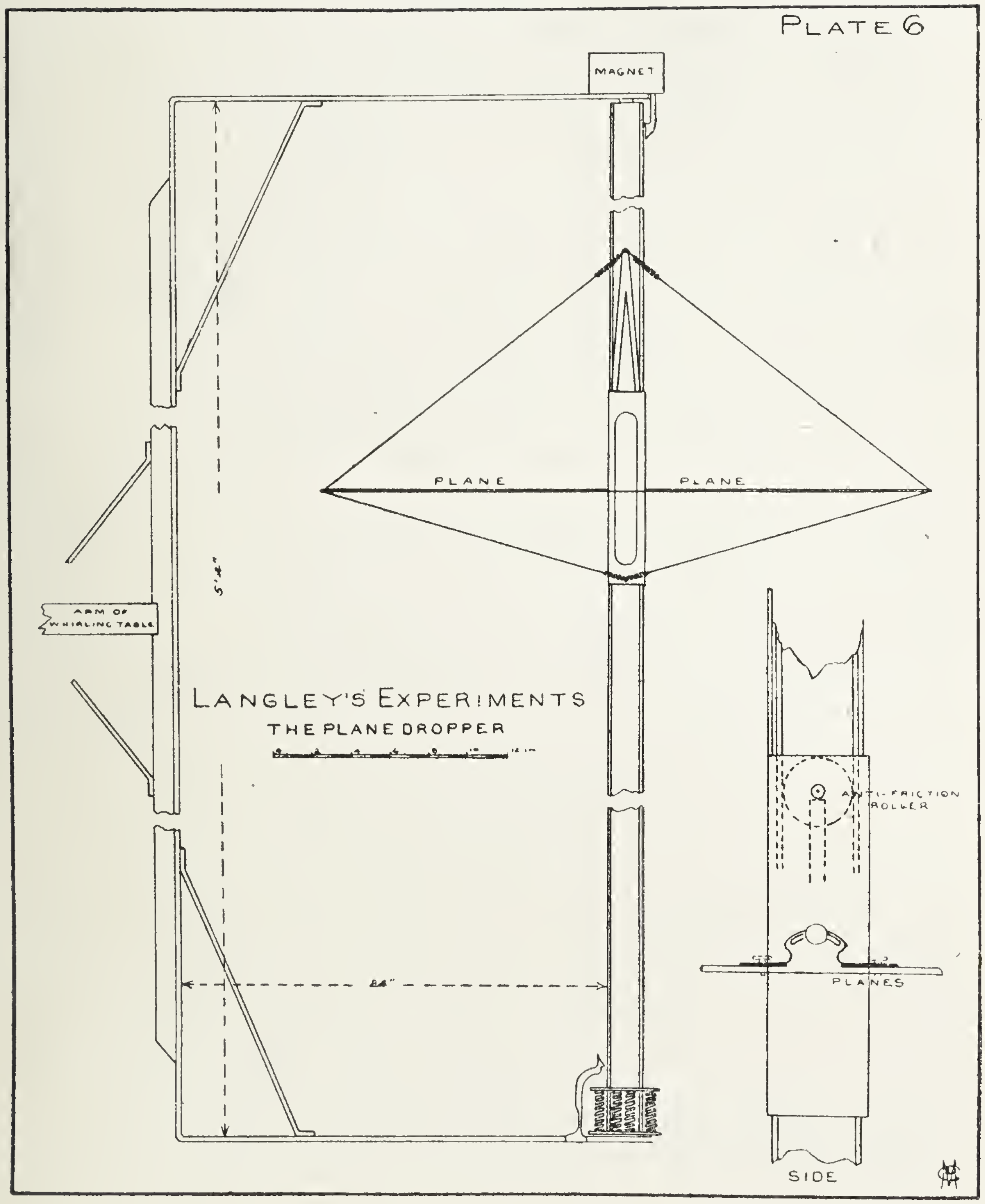
Probably the most important experiment made by Mr. Langley was that with what he called the "plane dropper." Its construction was simple. It consisted merely of a frame and standard, to be attached to the end of the table, provided with a set of vertical guides in which moved anti-friction rollers attached to a set of two horizontal planes. (See Plate 6). The planes being held by a catch at the top were released electrically, and fell some four feet, passing vertically down the guides and striking on a spring cushion at the bottom. The planes were capable of being inclined to the horizon at any angle up to 45°. Five pairs of planes were experimented on, ranging from 6 x 12 inches to 18 x 4 inches each, end weighing an average of 120 grammes per pair. The additional weight of the falling piece was 350 grammes, or a total of about one pound. The time of fall from the breaking of contact at the top to the making of it again at the bottom was recorded on the chronograph. This record, together with that of the rate of the table, the angle of inclination, and size of the planes, afforded a means of determining the sustaining power of the air with regard to speed and area. Mr. Langley made his experiments with a view to three results: first, to show that the supporting power of the air increases with the horizontal velocity, be the planes either horizontal or inclined; second, to determine what particular speed is necessary to produce for different angles of inclination a lifting effort sufficient for sustentation; third, to investigate similar facts with superposed planes.

No doubt, the easiest way to show the truth of the first is to furnish a diagram with the plotted results of the experiments; see Figure 2, Plate 7. The abscissæ are the horizontal velocities of translation in meters per second, and the ordinates the times of fall in seconds. These were made with two horizontal falling planes (18 × 4 inches), advancing long edge on to new air. The theory of this is similar to that before quoted of the skater on thin ice. Should the plane be at rest, only one unit of air serves to sustain; but, while in motion, a number of units act. These experiments show the great value of speed for the sustaining of a moving aeroplane. Mr. Langley has found that better results are obtained with the longer edges of the planes foremost; the reason is obvious, for the back parts of the planes are not acting on previously used air.

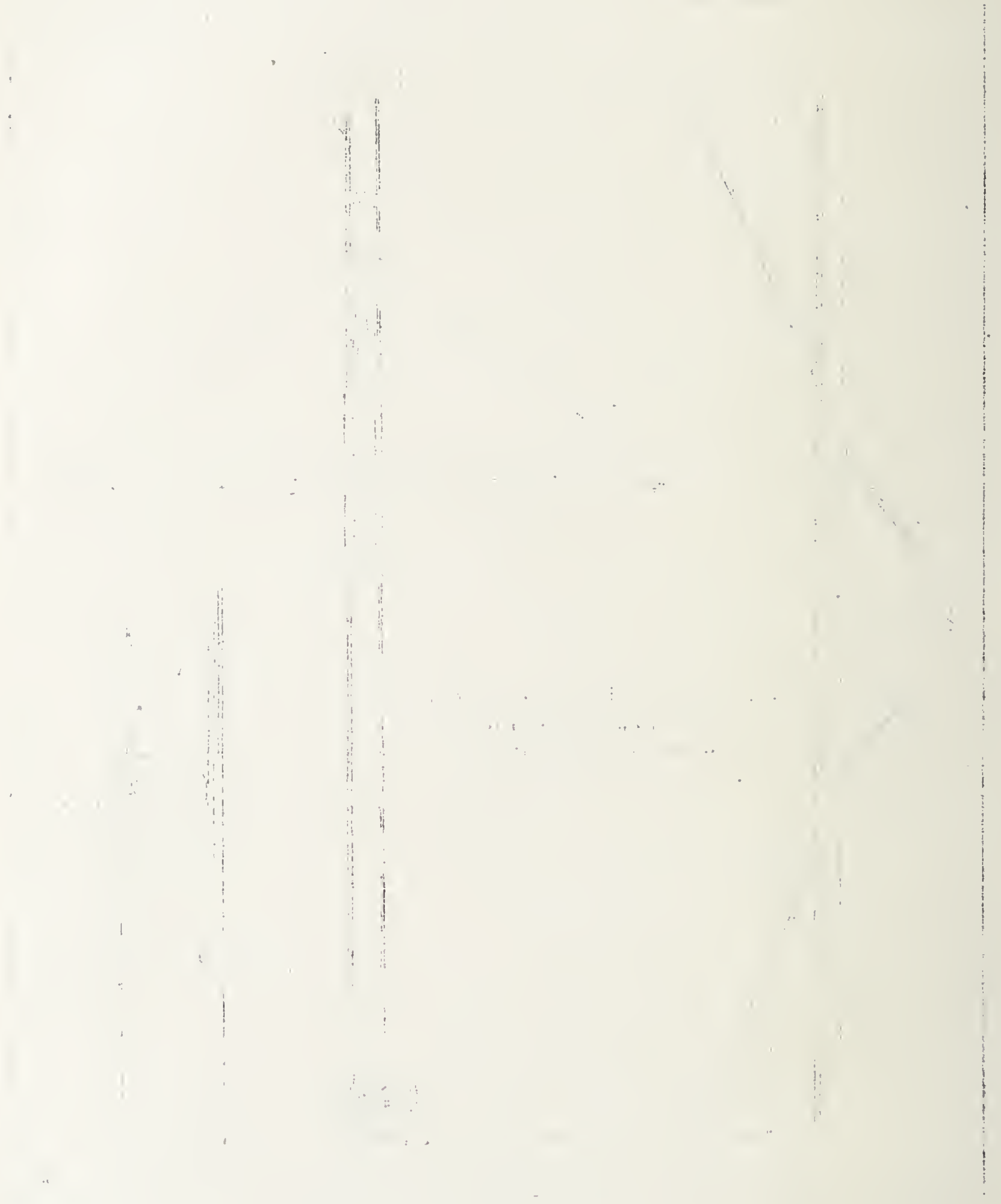
The relation of angle, speed, and lift is the very essence of the soaring aeroplane. It is evident that if the first law above is true, then there is an angle for each speed of translation which will continually maintain the aeroplane in the air. Mr. Langley actually made such experiments. He placed different planes at different angles, and then ran the whirling table at increasing speed until the planes were just merely supported. He was enabled, from the results, to calculate the respective horse powers acting. Figure 3, Plate 7, shows the plotted results of two sets, 18 × 4 inches and 8 × 9 inches, moving at different inclinations. The abscissæ are the angles of inclination of the plane, and the ordinates the velocities in meters per second. In regard to the third case of investigation, it was found that the closeness with which the planes could be set was a function of the speed; the greater the speed, the greater the relative proximity. The air seems to be disturbed under the aeroplane for only a slight depth, and this is the air which really might be said to do the work. The minimum distance with Mr. Langley's planes was four inches. At two inches, a decided diminution in the lifting power was experienced.

A result of prime importance is logically deduced from the preceding—this is that, with heavy inclined planes in motion of translation, the higher speeds are accomplished by less actual power than are the lower ones. This is surprisingly paradoxical, and the fact led Mr. Langley to continue his experiments directly for this purpose. He arranged an automatic apparatus, called a component pressure recorder, to be used in conjunction with a "dynamo-meter chronograph," for recording the speed, times, resistance to forward motion at the instant of soaring, the horse power, and other phenomena. The latter instrument was placed *on* the recorder, and was provided with an air screw propeller actuated electrically, and recorded its own work. The recorder was a combination of the resultant recorder and plane dropper, and was capable of recording the instant of soaring flight of its plane, the location of the centre of pressure on the plane, and the intensity of the horizontal and vertical components. The propeller was calculated to so actuate the whole recorder as to counteract the air resistance to the arm of the recorder on which it was situated. Knowing the power or pressure required to make the plane of the recorder soar itself, and reproducing this by means of the dynamometer, the power expended for different speeds, etc., was found. Thus the paradox was demonstrated experimentally.

PLATE 6



LANGLEY'S EXPERIMENTS
THE PLANE DROPPER



Similar experiments were conducted by Mr. H. S. Maxim at Bexley, England, and, it might be said, took up the work where Mr. Langley left off. Mr. Maxim also provided a whirling table similar to Mr. Langley's. The circumference described was 200 feet, and power was supplied electrically through the pivot to the end of the table. To briefly outline Mr Maxim's experiments : On the end of the whirling arm he mounted an aeroplane and an electric motor actuating a screw propeller, which caused the table to revolve. In connection he had mounted on the arm different dynamometers, so that he obtained a record of the thrust of the screws, the horse power exerted, the velocity of rotation, and the lifting effort on the aeroplane. He tested about fifty different kinds of screws, and also aeroplanes ranging from 3 × 24 inches to 3 × 12 feet. He concluded that long narrow planes, long edge on, slightly concave on the underside, and at inclinations of from 5° to 10°, gave the best results. Screws with two narrow blades of small pitch and with high velocity were the best. He was able, with the aeroplane running at 60 miles per hour, to lift 133 pounds per horse power.

The late Mr. C. W. Hastings has compiled the results of a number of experimenters into tables and diagrams which are too extensive to touch here. Some of his results may be mentioned, however. If the the area of the supporting plane is constant, the horse power required and the angle of inclination decrease with an increase of speed. If the angle is constant, the speed increases directly as the horse power, and inversely as the area. If the power remain constant, the speed increases with the decrease of both area and angle. The smallest angle is, therefore, desirable. " If the smallest angle which can be safely used be 5°, we see that if the speed be decreased from seventy miles per hour to forty, then the area required will be increased from 0.36 square feet per pound to 1.10, or more than three times ; while the power required will decrease only from 0.015 to 0.009 (per pound weight), or considerably less than one-half. This shows the advantage of high speed.

I have reviewed thus briefly the outline of the principal laboratory data which is the basis of aerial sustentation. In a paper of this kind it is well-nigh impossible to present any complete collection of information, and the foregoing must suffice.

We now come to the consideration of the theoretical and ideal flying machine—the requisites for its sustentation, propulsion, and stability. Such a discussion must be based, of course, on the foregoing data, and hence must be, in part, somewhat a conjecture, for with the exception of the renowned Maxim machine we have no actual working data at hand.

The requisites for a flying machine may be summed up as follows:

(1) Its various parts and members must be of the lightest construction compatible with strength and stiffness, and the factor of safety must be large.

(2) Its general configuration must be economical for space and convenience, and present the least possible resistance to the air.

(3) It must be capable of rising gently, but swiftly, and supporting itself in the air in storm or calm, for a length of time.

(4) It must have stability and be incapable of upsetting.

(5) Should be easily steered in any direction.

(6) Provided with a means of rapid and powerful propulsion.

This enumeraton may appear highly idealistic, but the practical possibility is much clearer than is generally supposed.

Taking the first division above—that of its mechanical construction in regard to strength and weight. Just where the useful limit of the compromise between these two conditions is remains to be determined for the greater part experimentally. The basis of such, however, would rest on the primary comparative value, weight for weight, of different materials. Let us first look at different working machines in this regard. A man will exert about one horse power for 1000 pounds weight, or, working continually, can put out about one-sixth of a horse power. Animal muscle is seldom subjected to more than 100 pounds per square inch tensile, and in ordinary 20 pounds. Thus the factor of safety must be very high. A draft horse weighs 1,500 pounds per horse power, a marine engine about 300 pounds, a locomotive about 150 pounds per horse power. Birds, as far as can be learned, exert one horse power for perhaps 20 pounds. Anything better than the latter in mechanical construction would have been thought impossible a few years ago, but it is already surpassed by actual results. Munro's yacht "Norwood" is run by boilers and engines of nineteen pounds per horse power. Langley has built an engine at the rate of twelve pounds per horse power, and Maxim has an engine of 300 horse power, which with boilers and all apparatus weighs not more than six pounds per horse power. Hence it is seen that the problem of the weight of the propelling machinery is solved even beyond our hopes, for it has been previously predicted that could we design a motive power at twenty pounds per horse power the success of aerial flight is all but a fact. Mr. Maxim's engine is built of the very finest tool steel, and all possible parts are made hollow, with the very best workmanship and the greatest care. It is to be noted, however, that he states his engines to have cost their weight in silver.

Professor Thurston says :—"The reduction of weight may be accomplished by advances in either or all of three directions: (1) Reduction of weight of material by improved design and proportions; (2) increase of ratio of strength of the materials used to their density; (3) increased velocity of motion of the moving parts of the machinery transmitting energy." Much has been claimed the past years for the new aluminum. Aeronautical research has shown a great part of this to be a fallacy; the reasons are well known without detail here. In regard to the relative value of materials, we have the following table compiled from Langley, Hunt, and Hall :—

Metal.	Weight of one cubic foot.	Tensional strength per square inch.	Length of bar that just supports its own weight.
Cast Iron................	444 lbs.	16,500 lbs.	5,351 feet.
Ordinary Bronze...........	525 "	36,000 "	9,874 "
Wrought Iron	480 "	50,000 "	15,000 "
Hard Struck Steel.........	490 "	78,000 "	22,922 "
Aluminum................	168 "	26,000 "	22,285 "

This clearly decides for hard steel in construction where combined strength and lightness is required; which means, then, that all framing of a machine requires hollow steel rods, steel wire guys and bracing. Castings and drop forgings of steel are, apparently, better than any kind of alloyed aluminum yet made. Piano wire steel has been drawn to a tenacity of even 300,000 lbs. per square inch. Certain alloys of aluminum, with copper and nickel, have been very successful in regard to strength, but there yet remains the difficulty of working the metal. Wood may be used under circumstances, but, in such occasions, attention is directed to the increased air resistance which might arise. It is needless to point out that the factor of safety, under all conditions, must be large.

There is not much to be said on the subject of configuration outside of the air resistance. Our best models for such are the bird and fish. Each of these present a very small forward resistance. Their lines and surface friction are such that the resistance may be almost zero. This is the reason that most aeronautic constructions built for speed are elongated, or "cigar" shape, as we know it. The balloon "La France" measures 165 feet in length, and 27.5 feet diameter, the maximum transverse cross-section being at about 40 per cent. of the length from the front. For a flying *machine*, however, the circumstances would be much altered from those of a balloon. If the sustaining apparatus be a rigid aeroplane, the forward resistance will be limited, for the greater part, to the car and machinery section, although, by the way, the resistance of bracing, etc., has been found to be surprisingly great. In such a machine, then, the forward part of the "deck" might be protected by a light construction of fine lines which would cut the air with the least resistance, and divert the wind current from all deck apparatus but the propellers. In such, however, the division of the currents should not be great enough to effect the efficiency of the propellers, aeroplanes, or steering apparatus. As for the economy of space, that would necessarily take care of itself in the economic mechanical construction.

We now consider a requisite which is of vital importance, and which will require a lengthy discussion—that of the supporting power. In this we will merely consider the theories in regard to the "soaring" machine. The controlling conditions of such aerial support are quite dependent on each other. They may be summarized as follows: (1) The weight of the machine; (2) the area and character of the supporting surface; (3) the angle of the supporting surface; and (4) the velocity of forward motion, and, consequently, the power.

In considering the supporting power of an aeroplane, we must always bear in mind the fact that the upward impulse is directly dependent upon the thrust of the new air on the underside of the plane. We have seen how the laws of such pressure are deduced. It is true that they have been made on a small scale on small planes, but the concordance of the experiments leads us to infer that they are similarly applicable to larger areas. The air is such a very light and mysterious substance that not only does difficulty of experimentation arise, but it will be a long time before man will realize that its supporting power is something quite material. Those who have really been up in the air in a free machine tell us that we "cannot imagine what a delightful sustaining power there is" in the air. We have seen how the sustaining power depends on the angle of inclination of the moving aeroplane, and the velocity with which it is propelled. If we follow out the principle presented in the table on soaring birds, we could arrive at a series of tables for the weight which would be sustained by one square foot of aeroplane moving at a known rate and angle. We have seen, in Plate 7, how the sustaining power is a function of the normal pressure, and how the power increases with small

PLATE 7

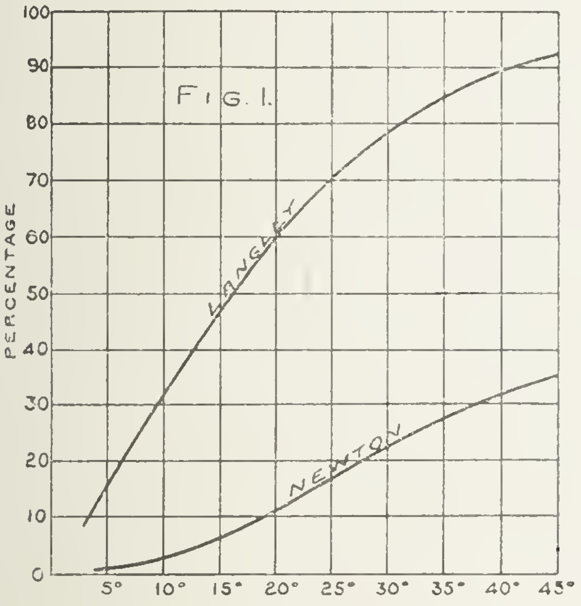


FIG. 1.

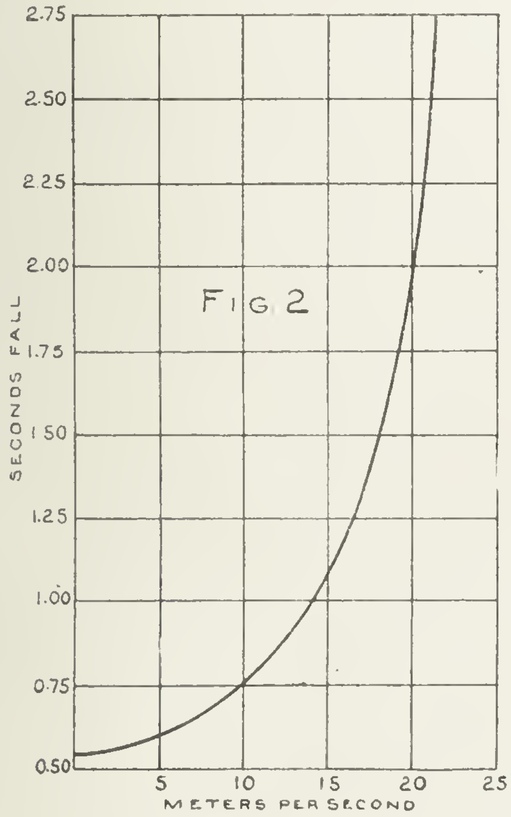


FIG. 2

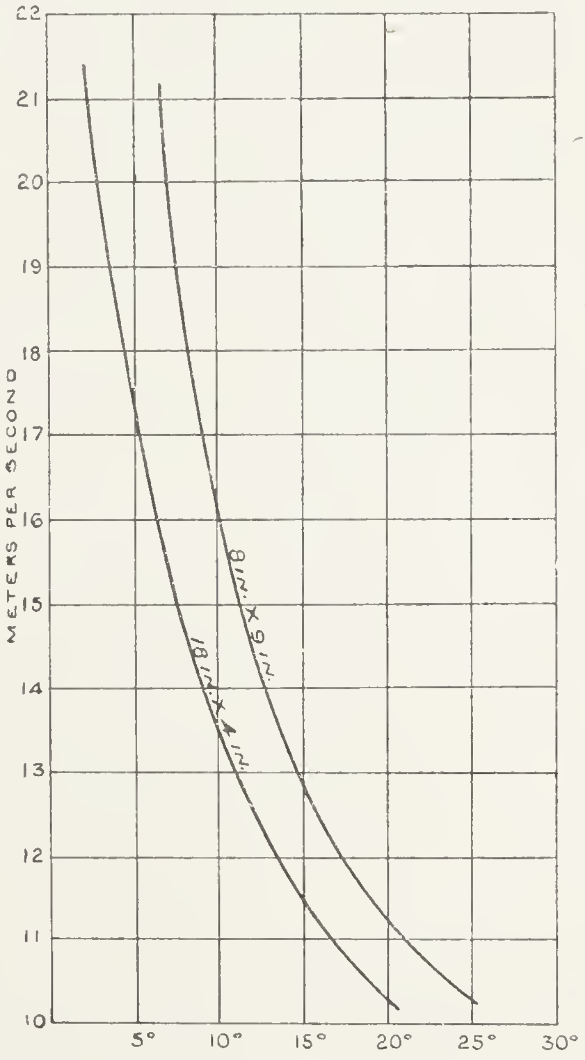
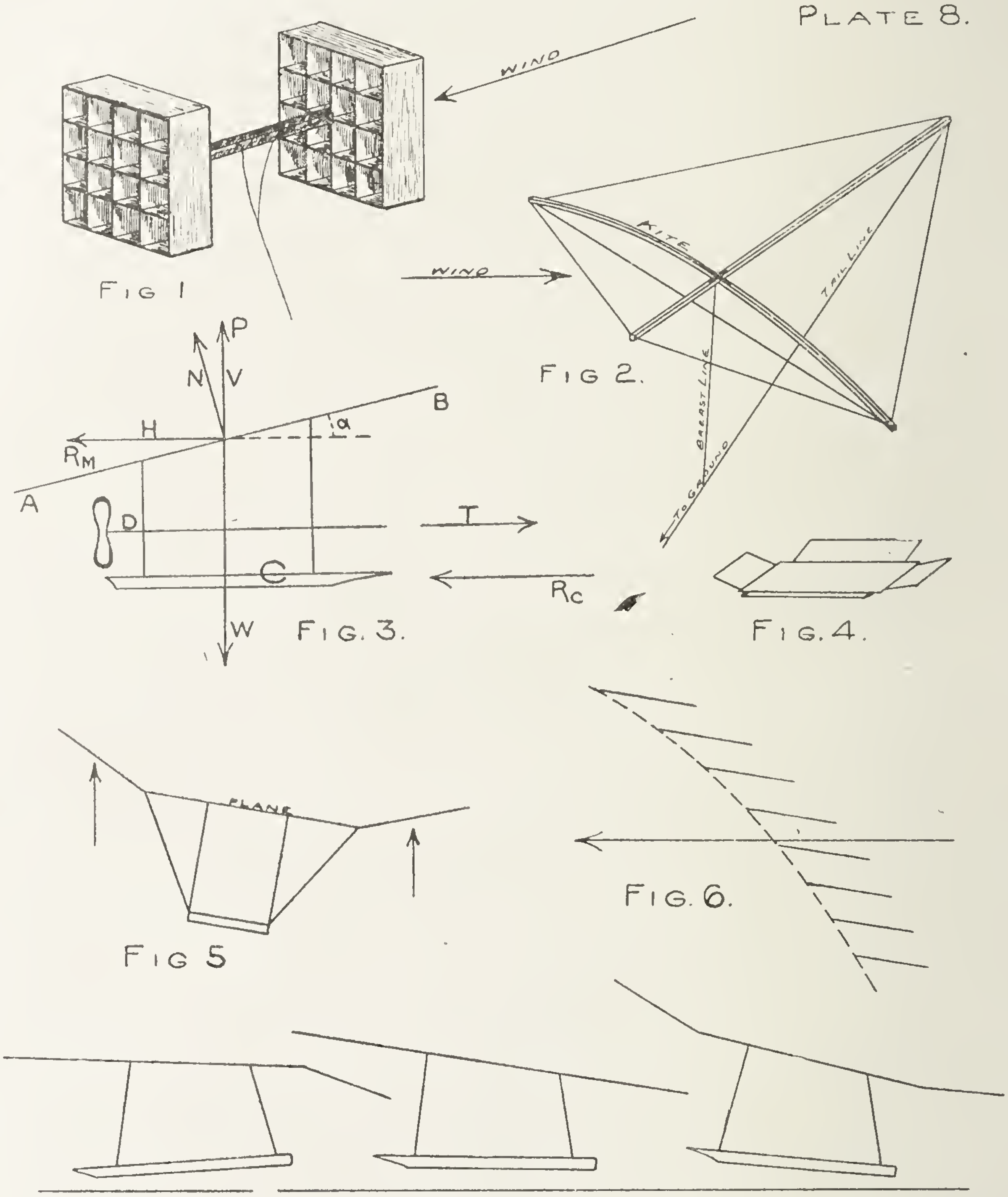


FIG. 3

PLATE 8.


WIND
FIG 1
WIND
KITE
TAIL LINE
BREAST LINE
TO GROUND
FIG 2.
P
N
V
B
H
α
R_M
A
D
T
C
R_C
W
FIG. 3.
FIG. 4.
PLANE
FIG 5
FIG. 6.
FIG 7

angles and high velocities. Experiments have led us to believe that inclinations of from 5° to 10° are the most serviceable. True, better results might be obtained by smaller angles, but the stability of the machine in a longitudinal direction would then be endangered. Let us look at the mathematical considerations for an aeroplane, with car, etc., attached, passing through the air. In Figure 3, Plate 8, let AB be the aeroplane, C the car and apparatus, and D the propelling machinery. Suppose R_c be the air resistance of car and attachments, W the weight of the machine, and a the angle of plane. Then we have $N \cos a = P =$ the vertical sustaining force where N is the normal pressure of the air caused by the velocity. $N \sin a = R_m$, the horizontal resistance to motion of aeroplane. If L be the thrust of the air on the underside of the plane, then $L \cos a = V =$ vertical part of wind pressure, and $L \sin a = H =$ horizontal part of wind pressure. Let $T =$ the thrust required for propulsion. Then we have the following conditions of equilibrium and motion of the machine: $P + V$ and W must act through the centre of pressure of the plane. The centre of gravity must be below the centre of pressure or lift. The thrust T $\text{must} = R_c + R_m$, and when $P + V = W$ the machine will proceed horizontally. When $P + V$ is greater than W the machine will rise, and when less it will fall. With increased velocity or T the machine will rise, and *vice versa*.

By means of the Langley formulæ and diagrams, together with those of De Louvrie and Duchemin, we have a definite formula for the ratio of up lift and forward motion with regard to the normal pressure on an aeroplane of known inclination. For instance, where the normal pressure on an inclined plane is expressed as a percentage of that on a vertical plane, we have with an angle of, say, 8° the normal pressure 0.260, the lift 0.257, and the resistance to horizontal motion or "drift" 0.036, by the De Louvrie formulæ. By this means we can arrive at the extent of the supporting surface to carry a given number of pounds. Let us look at the number of square feet per pound required under different conditions. Referring to the accompanying table of birds, we see that the rate varies from 3.191 square feet per pound for the night hawk to 0.442 for the wild duck. Good soaring birds, such as the petrel (0.833), pelican (0.737), stork (1.406), and tawny vulture (0.682), lead us to believe that we ought certainly to fly with a machine carrying one square foot of sustainer for every pound weight. It is with this assumption that experiments have been actually made, and we will see further on how this rate has been much surpassed.

It has been pointed out how we may consider the support by means of an aeroplane as being obtained by driving the *new* air downwards. Considering the subject in this way, we will see it much clearer. Suppose we take the formula $\frac{WV}{g}$, so well known, where W is the weight of the mass of fluid acted upon in pounds per second, V the downward velocity in feet per second, and g as 32.2 feet per second. To illustrate this, let us consider the power expended to do the work. Take two machines each weighing, say, 1000 pounds. Let one be capable of being run so as to act on, say, 2000 pounds of air per second. Then $2000 \div (32.2 \times 1000) = 16.1$, which is V or downward velocity. If now we determine the horse power to accomplish this alone, we have $W \frac{V^2}{2g} \div 550$, or $\frac{2000 \times 259.21}{64.4} \div 550 = 14.64$ horse power. Suppose, now, we double the quantity of air acted upon, we have $V = 8.05$ feet per second, and $\frac{4000 \times 64.8}{64.4} \div 550 = 7.32$ horse power. The significance of this is apparent, that much is to be gained by acting on a large quantity of air. Such can be accomplished in two ways, either by velocity (which fact we have seen before) or by large aeroplanes. The figures as given above refer, of course, to propulsion as regards the aeroplane alone, and not to car resistance.

It cannot be too strongly urged that the aeroplane must be driven on to new air previously undisturbed, that this air must be driven downwards, and that at a fast rate. As has been before intimated, the lifting effort with regard to the thrust is found to be very much greater than was hitherto supposed. The figures from the De Louvrie formula above will show this. The lift is seven times the drift or thrust horizontally; that is to say, if the propellers of a machine gave a clear thrust of one foot, the lifting effort produced would be seven pounds, with an aeroplane at an angle of eight degrees. This fact has been already borne out experimentally.

From the foregoing, it can be readily seen that the problem of actual flying is very easy of solution; that a machine, once up, can be propelled with a minimum amount of power, provided the velocity be sufficiently great. The power is required at the rise, and that is where the difficulty will always present itself—to say nothing of the descent. If the angle of an aeroplane be rigid, and the machine be constructed so as to rise by a forward thrust, the angle, when rising, will be much greater than when proceeding in horizontal flight, the speed cannot be so great, and there is an additional effort required against gravity, so that a great deal of power is consumed. By any scheme of aeroplane it is a practical necessity to rise in this way by a forward impulse—riding *up* on the air, as it were. Some experimenters have suggested screws revolving on vertical axis, expecting thereby to raise the machine vertically, so as to avoid the horizontal running start, as they call it. They forget that with rigid aeroplanes such a procedure is very difficult. If it were possible to automatically collapse the aeroplanes, the case would be different, but a direct rise otherwise would require a very great displacement of air. Professor C. V. Riley has suggested propellers moving on shafts which can be turned through a quadrant, from vertical to horizontal, at will. The consensus of opinion, however, leads us to expect that rising will be effected by a gentle forward and upward progress. Suppose, we will say, that the rise, after leaving the ground, will be at an angle of 20°, then our aeroplane is encountering the air at an angle of, say, 28°. In such a case, by reference to De Louvrie, the normal pressure is 0.751, the lift 0.662, and the drift 0.354, so that only about two pounds could be raised per one pound horizontal thrust. If rising at an inclination of 10°, the upward thrust would be over three pounds. If it were possible to arrange a system of aeroplanes which could be adjustable to such circumstances, much power might be saved.

Much ridicule has been hurled at the flying machine in regard to its ability to descend to earth—very much like the Irishman who didn't mind the falling, but objected to the sudden stop. In reality such difficulties are, perhaps, more imaginary than real. Suppose we have a large aeroplane, and that we have wings, as it were, on each side at an inclination, as shown in Figure 4, Plate 8; and suppose our propelling power is suddenly stopped in mid-air. The whole would *settle* to the earth like a parachute, and would land with little shock. Landing under such circumstances would soon become a matter of practice. This will be spoken of further on under stability.

Altogether, it appears to be generally conceded that the aeroplane system offers the best supporting power, the swiftest and gentlest method of ascension, with the simplest attachments, therefore, that has as yet been investigated.

Let us look now, briefly, into the character of the supporting surface. Hitherto we have been treating the subject of the aeroplane as if it were one plane upon which the wind was acting. This was done for simplicity. It may be said that there are two systems of aeroplanes which are advocated. The one, that of the very large aeroplane alone, with the necessary side planes and rudders, of course; the other that of a series of long narrow planes arranged to advance long edge on the air at the necessary angle. The first system has the advantage of being very simple, and offering, probably, a more stable and safe support, due to its parachute properties. Maxim is the leading disciple of this system. The second system has grown out of Langley's experiments, which show that the best results to be obtained for soaring are with the narrow planes. It will be remembered that Langley made his experiments on real planes for simplicity. It is to be desired, of course, in the aerial construction, that all supporting planes be concave on the underside. This is more easily accomplished by the series of narrow planes than by the single large one. The large plane must be so placed as to not interfere with the action of the propellers or steering apparatus in shutting off the air or creating an adverse current. It has been suggested to arrange the narrow planes in a superposed series similar to that shown in Figure 6, Plate 8. Each narrow plane thus gets new air, which does its work quickly, and passes off at the back end. There is less loss at the sides, too. The intervals between planes should be considerable, at least the same as the width of the planes. One objection to this method is that the propellers, etc., if situated behind the planes, are not efficient, and, if before them, render the planes inefficient, while, if below, would make a cumbersome construction.

As to the materials for aeroplanes, experience seems to point to light balloon cloth or "gold beaters' skin" for exceedingly light construction. This can be stretched upon the very light metal or wooden framework of the plane. It has been urged, however, that this material is too frail, and that something stronger is preferable. Oiled linen weighs about 2.6 oz. per square foot, and makes good material. A new material is suggested, and has been found very satisfactory—a wire woven web made of very light aluminum wires is varnished, and the interstices filled with a light elastic varnish, which altogether makes an impermeable web about one-fiftieth of an inch thick and weighing 3 ounces per square foot.

Sections 4 and 5, as mentioned in the requisites for the flying machine, might be treated together under the head of steering and stability. Steering horizontally is probably most easily accomplished by the use of twin screws, as in sea vessels. The steering vertically is where our difficulty lies. We must remember that in aerial navigation we have all forces resolved into three directions, whilst in marine navigation there are only two. Vertical guidance can be effected in part by speeding the propellers —as pointed out in the conditions of equilibrium and motion. This, however, is limited, and vertical rudders, revolving on horizontal axes, must necessarily be used. In Figure 7, Plate 8, is shown the effect of the rudders, as illustrated by the Maxim machine. Here there are fore and aft rudders, each with its work to do.

The matter of stability is of vital importance. As previously intimated, the centre of gravity should be as far below the centre of lifting effort of the machine as possible. This is easily obtained with a machine of the Maxim type, the former being down near the deck and the latter up in the aeroplane. There is one fault which we are, perhaps, likely to overlook in our idea of the ideal machine, and that is an extreme in weight. If the machine is *too* light, it will be clumsy, and will have small momentum; its stability will be lessened, and it will be liable to topple over in the first gust of wind. The air is so subtle and light that we must expect great difficulty in providing a steadiness of motion. We know the birds retain their equilibrium intuitively; it is affirmed that they sleep on the wing; and our balancing-apparatus, then, must be something of the same sort. It is frequently suggested to provide some automatic electric balancing agent to accomplish this, but so far no success has been attained. Recourse to additional planes seems to be the only solution.

For transverse stability—that is, the prevention of side rocking and tipping—an imitation of the bird's wings seems to be preferable. The bird can preserve his equilibrium by placing his wings at a diedral angle from his body. This is such that if the body tends to rotate about a longitudinal axis, the wing which descends receives additional pressure from the air on account of its position, whilst the upper wing, being very much inclined upward, receives so much less. This principle is followed in several designs of machines now being tested. If side planes were projected, as shown in Figure 5, Plate 8, from each side of the main aeroplane system at an angle with it, they would attain this end. This condition is observed in boat building, but, besides, the boat has a keel—why not the air ship? Such would tend to prevent the rocking motion, though it would not help the supporting members. If the machine were sustained by the compound aeroplane system, the matter of transverse stability is simpler on account of their arrangement. Now comes the stability about a vertical axis, the prevention of a tendency to move in a horizontal circle or oscillate horizontally. This might be caused in a ship with twin screws, or where one side is heavier than another, or by a side wind. A couple is formed about the centres of pressure and gravity, and the ship may advance, perhaps broadside on. A keel and a controlling screw speed or a rudder for horizontal steering ought to prevent such; at any rate an attentive hand "at the helm" is required.

As for longitudinal stability—that is, the prevention of a fore and aft motion—it appears to be the most serious problem in this connection. There is less opportunity for experiment, which, with the fact that the fore and aft motion is limited in the aeroplane machine, renders our chances less. A number of things endanger longitudinal stability—the speed of propellers, head winds, sudden shifting of centre of gravity, and rudders. Much has been written upon this part of the subject, but as yet no definite information is at hand. Some advocate a horizontal keel like the fins of a fish, others a judicious manipulation of fore and aft rudders (see Plate 8), an automatic shifting of the centre of gravity, or the speeding of the screws. All of these have objections, and it is hardly likely that the problem will be solved until practical mid-air trials are made. In the Maxim ship with large aeroplane, although there has been no opportunity to make actual tests, it is observed that this stability is preserved in part automatically by the shifting of the centre of pressure, which, with the centre of gravity, forms a turning movement tending to right the ship.

The last requisite, but by no means the least, for the ideal machine is the propelling apparatus. I do not propose to go into this at any length, for it would require much space. All propelling apparatus can be divided into three parts: (1) The propeller proper; (2) the motor; and (3) the agent actuating the motor. Of propellers, there may be three kinds: The feathering paddle, similar to the marine one; the wing or oscillating fin, similar to the flapping birds; and the screw. For obvious reasons, the screw receives by far the greatest attention, and appears to merit it. The screw is capable of marvellous things in the water, and similarly should give the best results in air. To go into the theory of the screw is not the intention here, but the peculiarities of its action in air should be pointed out. The greatest drawback to the efficiency of the air screw is the very great "slip." The tendency is, of course, for the screw to become nothing else than a blower or centrifugal fan, forcing the air backwards. It is imperative that the screw advance upon fresh, undisturbed air, and that it act upon as much of it as possible with the least amount of disturbance. We know that a motion of translation imparted to the screw will decrease its efficiency. We also know that the pressure on the screw blades will vary as the square of the speed, and consequently the efficiency will vary inversely as the speed. The efficiency will vary also inversely as the angle of pitch, and directly as the square root of the area. The thrust of the screw will vary directly as the area and speed. Hence, we may infer that large screws with small pitch and velocity should give the best results. This seems to be correct in experiment, except in the velocity.

As for the motor much also might be written. Three kinds are suggested—the steam, the gas and the hot-air engine, and electric motor· The first may be of two divisions—the ordinary steam engine and the steam turbine. It is toward a suitable motor that, perhaps, the greatest energies have been bent in striving to solve the problem of flight. Success appears to be at present resting on the ordinary steam engine. Electric motors are not yet perfected, and storage batteries are out of the question on account of their weight. Hot-air and gas engines are also too heavy. This leaves us the two steam motors. Much is expected of the steam turbine, but as yet very little progress has been made with it; there is no doubt it will form a most efficient motor for aeronautical purposes. The steam engine forms, then, our most reliable motor. It is a machine which we know much about, and is reliable and powerful, and can be constructed of comparatively small weight. Closely allied with this is the agent actuating the motor—in this case the steam boiler. Research in the steam engine has also included this. It is needless to point out that the boiler must be of special pattern and construction; it must work under high pressure, make steam quickly, use a minimum amount of fuel —liquid, of course—and, like the marine boiler, work equally well in unstable conditions. With the steam plant goes the condensing apparatus, the pump and injector system, and the fuel feeding apparatus, together with the fuel and water storage reservoirs.

In speaking thus far of the propelling apparatus, we have been considering only the conditions affecting a large machine, and we have not paid any attention to the single or individual machine, the parallel of the bicycle—the former may be likened to the railway train. There is no doubt that the time is coming when we will have machines of one-man power navigating the air. The power will probably be supplied by the foot pedal similar to the bicycle, though a man cannot generate more than 0.2 horse power for any time. We may find perfected gas engines of simple construction which, by the aid of chemicals, will furnish small powers for propulsion.

We have now come to the consideration of the progress made thus far in the flying of actual machines. To describe the varying fortunes of these would probably quite comfortably fill a large book. Langley and Hargrave have each designed and successfully flown model machines, but I do not propose to present the principles of these in this connection. I would direct attention to the two great types of machines which are now before the world seeking success, which, it may be said, appears to be not far distant. These are the Lilienthal soaring machine and the Maxim flying machine.

Herr Lilienthal has, since 1890, been performing direct experiments on an apparatus to be attached to the body of a man, by which he is enabled to soar or gently descend from a high elevation to the earth. Previous to that time he had directed his attention to the solution of certain problems of construction and to experimenting upon the supporting power, especially of curved surfaces. During the year of 1893 he attained considerable success with his machine, and astonished the scientific world with his marvellous feats. These were nothing more or less than a gentle gliding downwards against the wind at the least possible angle to the horizon ; that is, covering the greatest horizontal distance. Lilienthal believed that the only way to successfully solve the flight problem was to follow a purely tentative method, and having hit upon a simple contrivance of supporting surface similar to that of the soaring bird he proceeded to try his wings, as it were, in a very humble way. He succeeded in soaring downwards on a hillside against the wind, passing only a few feet above the surface. This simple beginning has been the stepping-stone to great things, and he is now nabled to ride long distances on the air in a gentle breeze.

His apparatus consists essentially of three members—the wings, or aeroplanes, a vertical rudder, and a horizontal rudder. The framework is so contrived that the wings can be elevated, lowered, or folded backward. The rudders are manipulated by the operator directly ; the horizontal one being immediately behind him, between the wings ; and the vertical one further back still. The horizontal rudder serves to act as a sustainer also, and closes the space back of the wings. The operator rests on a cross-arm, between the wings, either by grasping it, or placing it under his arms ; in some cases he has arranged a seat. The wings and other sustainers are built of a very fine muslin, washed with collodion to make it impermeable to air, which is stretched on a very light but strong framework of split willow or bamboo. In the apparatus which gave the best results, the wing surface was about 150 square feet, having a total spread of 23 feet, and a width of wing of 8.2 feet. The whole weighed some 44 pounds, which with Lilienthal's weight placed the total at 220 pounds. The concavity of the wings is a point on which he lays unusual stress ; it certainly would have been impossible for him to accomplish his feats had the wings been planes. He points to the birds, of course, for his proof. Just here it may be mentioned that Lilienthal was among the first to insist upon the concave sustainer. He was somewhat ridiculed, but of late the experimenters have been looking favorably on it. It is unfortunate that Langley has not given us any data on curved surfaces, but that fact does not signify that he has no belief in their value. The great value of concavity is its power of stability, which is exemplified in the Lilienthal experiments. The sustainers were given a concavity to conform with the parabolic curve so common in the bird.

The relation of weight to surface can be pointed out by reference to the above figures. We see that he sustains in gliding flight alone one pound for every 0.68 square foot of sustainer. This is the same as the tawny vulture previously given, and shows the possibilities to which we may attain.

Herr Lilienthal gives special emphasis to the stability of his apparatus, and no wonder, for we can imagine how little there is between the passenger and a broken head. The framing is very rigid, and when once in the air and gliding forward descent is easy, unless a gust of wind comes to disturb the poise. When anything of that sort happens, requires quick and thoughtful action—a change of the centre of gravity, a movement of the rudders and wings, and that very carefully. The movement of the body—the head, arm, or foot—will suffice to alter the centre of gravity sufficiently to obtain the equilibrium. Lilienthal describes as follows:—"You run down hill against the wind with lowered wings; at the proper moment you raise the carrying surface up a little, so that it is approximately level; and then, springing forward, you try by a proper position of the centre of gravity of the apparatus to give it such an inclination that it will glide along rapidly and drop as little as possible." The legs hanging from below the apparatus are kept well in front, which tends to keep the wings on the wind. This part of the stability is assisted by the horizontal rudder, which prevents the whole machine from tipping forward, a motion which is quite possible with arched wings. In landing, he throws the upper part of the body directly backward, which tilts the wings strongly against the wind; in nature this is most noticeable when a heavy bird, such as a wild goose, alights. The rudders must be so arranged as to not prevent a rapid backward tilting of the machine when landing. Both the starting and alighting must be made dead against the wind, as in the case of birds.

The shifting of the centre of gravity by the movement of the body requires much practice; it must become almost automatic. Lilienthal says a beginner is too apt to move his feet or body to the wrong side when attempting to right the machine. Perhaps the operator soon becomes well used to his position when working against the wind, and he then tries to pass across it. It is here that nothing but practice avails—like bicycle riding. While in the air one has no time to consider just how scientifically he is manœuvreing, but the preserving of his equilibrium obtains all his attention. Altogether, this mode of flight is very much a matter of diligent practice, and success is to be obtained only by failure.

The science of the soaring machine is very simple, being identical with the soaring bird. There is very little mathematics, and that has been all discussed previously.

The greatest velocity of wind in which Lilienthal dared to start was about 16 miles per hour. Of course, the stronger the breeze, the least angle of "aeroplane" and flight will suffice. In a wind of, say, 10 miles per hour he could glide downwards at an angle of 8° with the horizon; in a calm he has even glided at an angle of 10°. In such a case, the wings are very slightly tilted, and he estimates the uplift to be 80 per cent. of the pressure, if normal. He attained about 30 feet per second, so that with a surface of 150 square feet he obtained a total uplift of 260 pounds; whereas all that was necessary was 220. With a wind of, say, 15 feet per second, and a gliding of 8°, the drop would be 2.1 feet per second, or the work by the ideal machine would be 0.8 horse power. Lilienthal is now testing a small steam engine of about 2 horse power, and weighing, all told, 44 pounds. By utilizing this, it will be seen that he will be enabled to accomplish *horizontal* flight against the wind. There are no reports of the trials yet to hand, but there is no doubt that success will be attained.

In Figure 1, Plate 9, is shown an elevation of gliding lines. The course A D was made in a strong wind, and at the culmination the apparatus stood for several seconds inert until the downward course was commenced. This was quite similar to the flight of birds already explained.

During the past few years the eyes of the world have been very attentively fixed upon Mr. Hiram S. Maxim, of Bexley, England. Without describing the events and experiments which led up to the construction of an actual flying machine, I will endeavor to describe some of the salient points of his air ship, which has won for itself such an enviable reputation. So much has been written in the papers and magazines that a detailed description seems hardly necessary, and I will leave the members of the Society to look up the subject, if they have not done so already.

PLATE 9

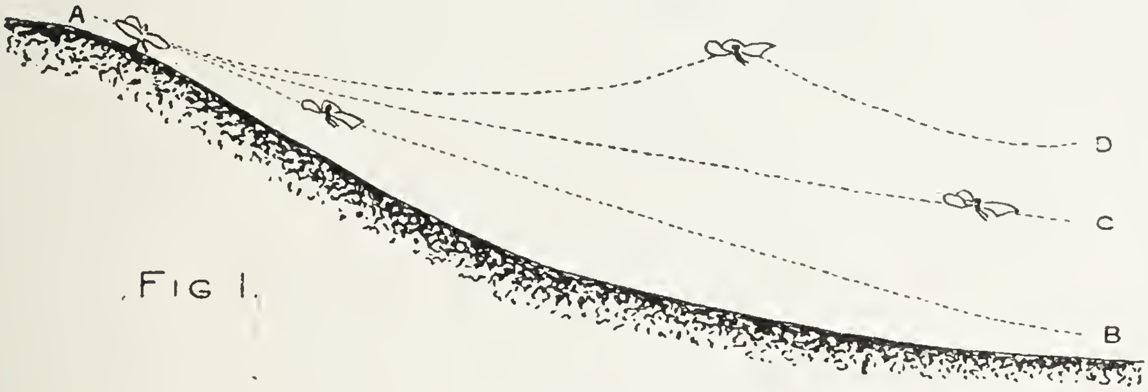


FIG 1.

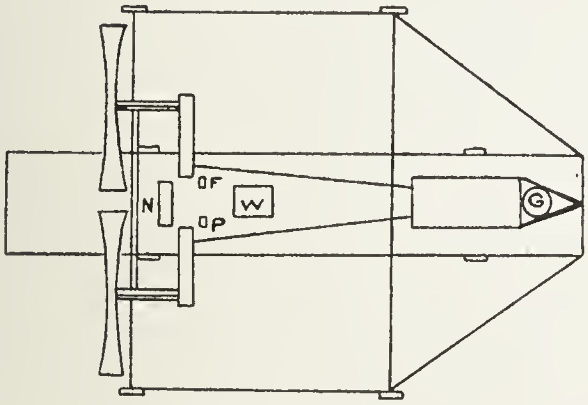


FIG. 2

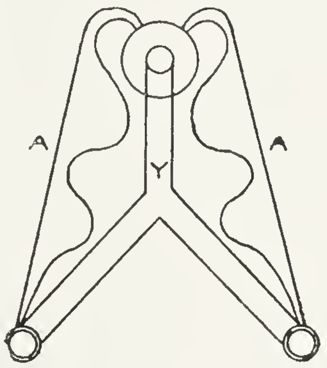


FIG. 3.

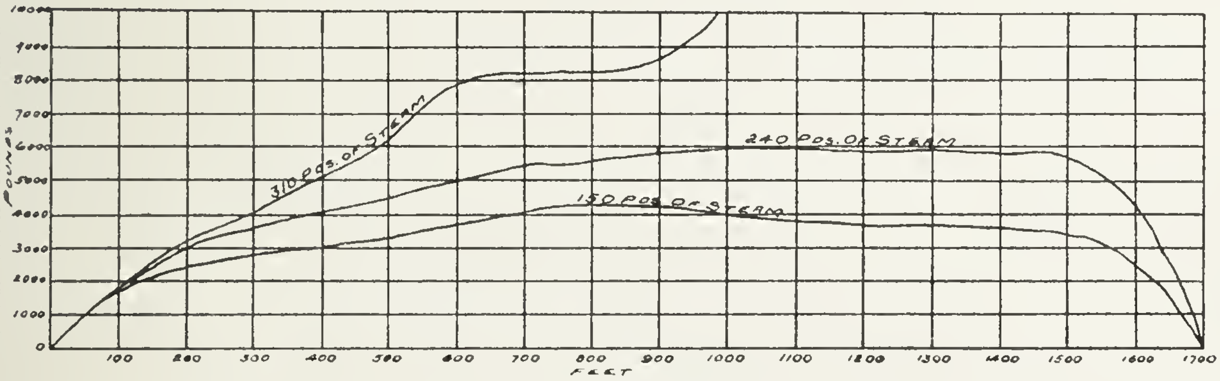


FIG. 4.

In his extensive park, Mr. Maxim has built a steel track 1,800 feet long, of 9 feet gauge, and outside of this a wooden *inverted* track, which may be known as an outrigger track, of 3 x 9 Georgia pine. It is upon these tracks that Mr. Maxim tests his machine. The body of the machine is a platform about 8 feet wide and 40 feet long, which rests on four steel wheels on the inner track. Upon this platform are mounted the engines, boiler, and all apparatus, together with the supports for the aeroplanes, etc. The main aeroplane is 50 feet wide and 40 feet long in the centre, and about 22 feet above deck. The framework of this is supported by means of hollow steel tube construction, thoroughly guyed and rigid with the deck. Fore and aft of the main plane are the rudders, hinged horizontally, and acting as shown in Figure 7, Plate 8; the forward one being 18 feet wide and 30 feet long, and the aft one 18 feet wide and 23 long. On each side of the whole structure extend side planes or wings for transverse stability, as well as for support. These are hung from the structure near amidships, and are superposed, their longer sides being transverse to the centre line of the machine. As these wings are 27 feet in length, the whole clearance width of the machine is 104 feet, and the total length would be about 93 feet. Aft of all the deck machinery are the propellers. The shafts are about 19 feet apart, are mounted 11 feet above the deck, and are run directly from the engines, which are placed at the same level. The boiler is at the forward part of the deck, and forms a windbreak for other apparatus. On each side of the platform extends an outrigger wheel system, which runs under the *under* side of the outer track, giving a vertical play of the whole machine of several inches. The centre of gravity of the machine is five feet back of the boiler and seven feet above the deck. (See Figure 2, Plate 9, for plan.

The engines are marvels of strength and lightness, weighing themselves only two pounds per horse power. They are a pair of high pressure compounds of one-foot stroke, and pistons of five and eight inches diameter. Each engine weighs 320 pounds, and the two together have exerted as much as 363 horse power, though only for a short time. The cranks on each propeller shaft are placed at 180°. The engines are placed transversely to the deck, the steam pipes being led in at the inner ends, while the propeller shafts are at the outer. Directly below the engines are the feed pumps and reservoirs, the one set for fuel naphtha and the other for feed water. The naphtha reservoir N and pump P supply the liquid fuel to the gasoline boiler G at a pressure of fifty pounds per square inch, being run by a belt from the port engine. In the gasoline tank the naphtha is heated, by products of combustion, to gas, and is fed automatically to the jets of the furnace. The feed water pump F and reservoir W are run by means of the other engine, and force the water into the boiler system at a pressure of about 330 pounds by means of an injector. There is also a device by which the rate of feed can be observed.

Not the least marvellous part of the apparatus is the boiler. It is essentially a water tube boiler of a remarkable type, resembling both the Thornycroft and the Yarrow, but much lighter. Figure 3, Plate 9, shows a diagram in section. The cold water comes in at the outer tubes (A) of the boiler (which form the feed water heater), at a pressure of 330 pounds, or 30 pounds more than that in the boiler. This difference is utilized in forcing the water (then at 250°) down through the steam drum by means of an injector, in which it carries downwards through the down-take Y the heated water in the bottom of the drum. This is carried directly to the heating tubes near the burners, and soon becomes steam. The outside tubes are of pure copper, and are $\frac{3}{16}$ inch inside diameter, and $\frac{1}{60}$ inch thick. The inside or real boiler tubes are also of copper, $\frac{3}{8}$ inch in diameter and $\frac{1}{50}$ inch thick, and are made to stand a bursting pressure of 1,650 pounds per square inch. Maxim says he has been enabled to get a horse power out of three of these tubes. There are about seven hundred tubes in the boiler, aggregating a heating surface of about 800 square feet. The furnace consists of some 7,600 gas burners, burning naphtha gas under a pressure of 50 pounds. Great difficulty was experienced in preventing the jets from blowing out. The boiler has been run up to 410 pounds pressure, but seldom is above 300, at which the engines easily exert 300 brake horse power. The motor requires 600 pounds of water and 200 pounds of naphtha for about one hour's run.

The boiler proper weighs 1,009 pounds, which together with 200 pounds of water inside, and the engines, gas generator, and pumps, puts the total weight of the motor up to 2,040 pounds (not including fuel, feed water, or condensers), with a total horse power developed of 363. The weight per horse power, then, is 5.6 pounds.

Mr. Maxim at first designed an extensive system of surface condensers, which was, in reality, nothing but the interiors of all the hollow tube construction in the flying machine, and most particularly that exposed to the air in the wings and planes.

After considerable testing of different screw propellers, a type was decided upon which appeared to give the maximum thrust with the minimum slip. These screws are two-bladed, 17 ft. 10 in. in diameter, and built of light American pine of the least thickness. The face at the periphery is 5 ft. 2 in. wide, and the pitch 16 feet. They are mounted on hollow shafts of 5 inches diameter, 5 feet long and $\frac{1}{8}$ inch thick. These screws are capable of driving the machine on the rails at 40 miles per hour, with 375 revolutions per minute. Mr. Maxim has estimated that out of the 363.63, 150 horse power is wasted in slip, 133.33 expended in uplift, and 80.30 in overcoming horizontal resistance when running at 40 miles. The horizontal thrust at that rate has been measured at 2,000 pounds, though it may be much greater before starting. On account of the great loss in slip, it is seen that the diameter of the screws is not great enough. Mr. Maxim thinks it should be at least 22 feet, and he is also making alterations in the framework to reduce the loss in resistance from 80 to 30 horse power. He has experienced no difficulty in the fan blower action of screws, for he found that his screws actually *drew in* air at the periphery, discharging it in a longitudinal direction. The first screws he built were of a pitch of 24 feet, which was found to be too great.

The aeroplanes were necessarily very carefully built. They were made of Spencer's balloon fabric tightly stretched upon a framework on both the upper and under sides. The underside was re-stretched a number of times, until it was as tight as a drumhead, and was unaffected by heat or cold. The upper one was not so tight, and permitted a certain circulation of air between. The fabric was lightly varnished with boiled oil. The main aeroplane was at an angle of one in eight in most tests. The upper side planes are hinged to the sides of the main one; whilst the other four on each side are attached to the bracing, one above the other. A very great supporting power is obtained with the side planes, though in the tests there were only several on each side. The total sustaining surface spread in the experiments aggregated 4,000 square feet. All the "aeroplanes" are true planes and not concaved; Mr. Maxim gives no very particular reason for this, though there is no doubt that better results might be obtained with the curved sustainer. He also departs to a certain extent from the teaching of experiment in exposing a very large main plane to the air instead of narrow ones. He claims, however, that one large one is a necessity, for stability's sake, but admits that the "narrow wings are found to be much more efficient than the main aeroplane itself." The rudders are directly controllable by levers at the engineer's hand, and these with the respective throttles of the engines place the steering gear in easy command.

In different parts of the machine are dynamometers for measuring the power exerted. Between the platform and wheels are calibrated springs in connection with a dynagraph, which records the uplift of the whole machine from the track. Indicators on the engines and dynamometers on the shafts record the horse power. There is also a speed indicator.

The weight of the whole machine, with water, fuel, and three men on board, was a little less than 8,000 pounds.

The Maxim machine exemplifies the true flying machine, accomplishing flight by motive power actually aboard, and not depending upon the wind. Mr. Maxim, however, does not wish his machine to be known as a flying machine as yet. He says :—" I don't call this an air ship, or anything else. To me, it is merely a machine for making experiments in aerial navigation." Nevertheless, this machine has actually flown. On July 31st, 1894, it raised itself, not only off the inner track, but from beneath the outrigger track, completely freeing itself. This is the first time any machine has ever actually lifted *itself* free from the earth, and, though an accident, marks an epoch in aerial flight.

No better description of the action of the Maxim ship can be presented than by reviewing the facts of the above accident of July last. Several previous runs had been just made with steam pressures of from 150 pounds to 240 pounds, and the machine was pushed back over the track to the starting place, at the workshop, and was tied up to a post and dynamometer. The screws were set going at an increasing rate, until they attained a speed of 375 revolutions per minute, and were exerting a horizontal thrust of 2,100 pounds. The pump was delivering 5,000 pounds of water to the boiler, and the safety valve was blowing off slightly at 310 pounds pressure. At this juncture the signal was given to let go, and the huge machine, with three men and all apparatus on board, shot forward at a frightful speed of thirty-five miles per hour. The steam was blowing off at 320 pounds pressure, and the speed of the screws increased. Having run about 500 feet, the machine was lifted entirely from the lower rails, and was running on the upper ones, the outriggers bearing all the additional uplift. When this occurred, the machine had lifted its own weight—8,000 pounds—and was really flying. At the 900-foot mark the rear axles (two-inch tubing) buckled, and set their outrigger wheels free, which allowed the aeroplanes to *decrease* their angle of motion, and consequently increase the uplift. Steam had already been shut off, but at the 1,000-foot point the uplift became so great that the left hand forward wheel left the safety track, and immediately afterwards the right wheel crushed the other outrigger rail, and the débris became entangled in the deck. The machine swerved to the right and landed fairly on the ground, imbedding the wheels in the earth, and did not move after it struck which showed that if the machine had been in the air it would have fallen directly.

Figure 4, Plate 9, shows a diagram of the lifting effort for three runs. The diagrams were made with the dynagraphs, and in the last run it will be seen that the pencil ran completely across the paper. The abscissæ show the distance travelled in feet, and the ordinates the uplift in pounds.

Mr. Maxim's device for stopping his air ship on the track is novel. At the end of the run the machine strikes against a series of ropes stretched across the track and connected with capstans in gear with revolving fans. These soon bring the ship gently to a standstill.

Upon the run in which the accident occurred the lift amounted to at least 10,000 pounds, though it could not be measured. The sustaining area was 4,000 square feet ; the sustaining power was, therefore, 2.5 pounds per square foot of surface—a fact which is surprising in the extreme, as we have no record of any flying creature of equal capabilities.

The fact that there is now a machine capable of surpassing nature in its *power* to fly or raise itself from the ground compels us to admit that the mechanical considerations, if not already successfully disposed of, are not far from realization. And yet, when we consider the relation of mechanical invention to similar natural machines, the surprise fades somewhat. Man has solved marine navigation in an altogether different method from that provided by the Creator, and he has attained, we may say, greater relative speed, perhaps ; at any rate, from the standpoint of power generation, he has surpassed the fishes. So on land. We have seen how the locomotive, the bicycle, and the electric car can surpass any natural means of locomotion, weight for weight. Why, then, is it to be wondered at that we should look for similar success in the other natural element—air?

Nothwithstanding this, however, the consummation of successful flight is still some way off. Man has made for himself a machine with which, we grant, he *may* fly, but it is not to be expected that he will be immediately able to manipulate it. No one would expect even the maker of a bicycle to be able to ride it upon the first trial. The fortunes of a flying apparatus depend on a purely tentative procedure, and in that direction only are we to expect success. Many persons have pointed out a means whereby this may be accomplished. Lilienthal takes a most practical way about it ; Mouillard suggests a very similar method ; whilst Mr. A. P. Barnett proposes a procedure somewhat like Maxim in riding an aeroplane attached to a bicycle on a level platform. Mr. C. E. Duryea gives us the novel suggestion of tying our machine below a captive balloon, and thus practising. Much might be learned also, theoretically, by the experiments on models by Hargraves. An idea has occurred to me which may also be of assistance in such safe experimenting, especially in our northern countries—that of running a machine such as Maxim's on the ice, similarly to an ice boat. This would greatly widen the field for practice. I have failed to see any similar suggestion, and have been somewhat surprised that it has not been made.

The perfection of aerial flight will come gradually, as did other perfected inventions which have revolutionized the whole world. We cannot look for any one man to thoroughly solve the problem, but it will be evolved from many sources, and these will at last contribute to the one long-desired end. At any rate, the age of blind and unscientific trial is now past; we look to science to solve the remaining part of the enigma, and we no longer expect signal failures of hopeful aviators who, like Icarus, venture too far.

Niagara Falls, Canada,
January 22nd, 1895.

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Jeremiah Head. . —“Locomotion in Air,” address British Assoc., 1894.
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G. C. Taylor . . . —“Flying Devices,” April, 1894.
J. D. Fullerton . . —“Design of Flying Machines,” July, 1894.
William Kress . . —“Theory of Sailing Flight,” June, 1894.
F. H. Winston . . —“Secret of Soaring,” Oct., 1893.

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C. W. Hastings . . —“The Problem of Aerial Navigation.”
J. Bretonnière. . . —“Gliding Flight.”
G. C. Taylor . . . —“Gliding or Soaring Devices.”
A. M. Wellington . —“Theory of Sailing Flight.”
A. F. Zahm . . . . —“Stability of Flying Machines.”
Lawrence Hargrave—“Experiments in Flying Machines.”
F. H. Wenham . . —“Suggestions and Experiments.”
R. H. Thurston. . —“Materials.”
C. E. Duryea . . . —“Learning How to Fly.”
A. P. Barnett . . . —“Methods of Experimentation.”

DISCUSSION.

Principal Galbraith.—The author is to be complimented on the excellence of his paper. It shows a very large amount of research in connection with a fascinating subject. It was the fashion not long ago to pooh-pooh work of this kind, but lately so many respectable people have taken an interest in aerial locomotion that it is no longer advisable to do so. The older attempts in the construction of aerial ships were based on what might be termed the fish idea. A fish is practically a body floating in a fluid of its own specific gravity, and capable of automatic motion. The former air ships were balloons floating in the air, and propelled by screw-fans. The more modern idea is to imitate the bird, viz., a body heavier than its surrounding fluid, and maintaining flight by utilizing the reaction due to swift motion. One of the difficulties in imitating bird flight arises from the fact that in the bird the supporting wings are also the propellers. In machines like Maxim's, on the contrary, the support is derived from aeroplanes, which are simply set like the sails of a ship, while quickly-revolving and comparatively small fans are depended on to produce the motion. If both functions could be combined in the same organ, there would be great gain in compactness.

Mr. Duff.—Mr. Mitchell has presented to us in a concise and interesting form all that has as yet been accomplished in aerial navigation. I feel that individually, as well as a society, we are greatly indebted to him for such a valuable paper, which will open up for many of us a new and interesting field for thought.

One question which occurs to me, and upon which I have been unable to arrive at any conclusion, is: Would the perfecting of aerial navigation be in the best interests of humanity and civilization? I know of no possible invention which would make so great a change in the life of the individual, or in the customs or organization of communities, as would the successful navigation of the air. The change would be so great that it is impossible to estimate its effects, and that they would be, in the main, beneficial is, to me, very doubtful.

However, it is a question which we need not as yet consider seriously.

Though much progress has been made in the construction and operation of flying machines, the greater part remains to be accomplished. The danger from sudden squalls, the necessity of moving at a high velocity, the uncertainty of the sustaining force, and, above all, our profound ignorance of the real course of air currents, seem to indicate that the successful operation of a flying machine is far more difficult than its construction. Icarus made himself wings, but he flew too near the sun and the wax melted. Maxim may build an air ship, but can he sail it? Bret Harte has a very amusing poem on this subject, entitled "An Aerial Retrospect," in which he describes his boyish attempts and experiments in ballooning, kite-flying, etc., and, amongst other things, how he

> "Launched from attic tall,
> A kitten and a parasol;
> And watched their bitter, frightful fall."

With the permission of the Society, I will read a short extract from the *Popular Science Monthly*, which explains itself.

AN EARLY DREAM OF AIR SHIPS.

"An essay by Roger Bacon, published in 1618, has been brought to attention by M. de Fonvielle, which contains dim predictions of steam power and the navigation of the air. 'Instruments,' the author says in this essay, 'may be made for navigating, without any men pulling the oars, with a single man governing, and going quicker than if they were full of pulling men . . . Wagons can also be made that, without any horse, they should be moved with such a velocity that it should be impossible to measure it . . . It is possible also to devise instruments for flying, such that a man being in the centre of revolving something by which artificial wings are made to beat the air in the fashion of birds . . It is also possible to devise instruments which will permit persons to walk on the bottom of the sea . . . All these things have been done in old times and in our times, except the instrument for flying, which I have not seen, and I have not known any man who saw it done.'"

MR. EDGAR J. LASCHINGER.—Mr. Mitchell, in his admirable paper on "Aerial Mechanical Flight," has opened up a field for wide and varied discussion.

Aerial navigation, the art of holding in subjection the powers of the air, of exercising perfect control over the motions of apparatus resting upon, and gliding over, its invisible yet sure support, has to this day existed only in the vivid dreams or pictured imaginations of its devoted disciples.

To navigate successfully, the mariner must adequately understand not only his vessel as to its capabilities, strength, and power, but also his ship's native element, the ocean, in its various moods and aspects, so that he may adapt the one to the other under all its varying conditions, with safety to himself and profit to the world at large.

Faith *grows* with knowledge, and knowledge with experience, aided by observation and reason; but practical demonstration *begets* faith, reason or no reason. The generality of mankind has no faith in aerial navigation, because no practical demonstration has been presented; on the contrary, the subject has been, and is, greatly ridiculed because of the many unsuccessful attempts by disciples of false doctrines of the art and disastrous consequences to ignorant, short-sighted, and reckless devotees. Although the subject has now for some years engaged the attention of scientists, very little is known either of the action of the air on the supporting surfaces of birds, which afford us our only successful models at present; and in spite of eighty years of history of ballooning, the laws governing the motions of our aerial sea, with its billows, currents, and counter-currents, are not understood.

The sciences of anemometry and aerodynamics being thus in their undeveloped state, principles are advanced with trepidation, and most of them lie in the realm of conjecture; this dearth of reliable data precludes the manufacture of any machine with a reasonable expectation of approaching success. The tentative method pursued by Herr Lilienthal is therefore commendable, and lies on the highway to success if supplemented by the application of experimentally determined data and established principles.

Since rapid locomotion on land has been affected by a departure from nature's methods, and since the screw propeller has no analogue in all her wide domain, the problem of aerial navigation will, in all probability, require, for its ultimate successful solution, instruments of propulsion, or even sustentation other than wings, but learners should study objectively.

Many theories have been advanced to explain bird flight, more especially soaring flight, which the bird accomplishes with such grace and ease, but which presents a harder problem and darker enigma than the quick, complicated actions of flapping flight, so tiring to the bird. No two theorists agree perfectly, but the following statement is fact: *an aeroplane absorbs energy only from a variable wind.* In a theoretically steady breeze (no wind is absolutely uniform either in velocity or direction), the necessary change of wind velocity acting on the surface may be obtained by changes in direction of flight, such as "circling," etc., to the formation of "relative squalls."

The amount of energy absorbed from a variable wind increases with the mass and spread of the plane, large, heavy planes being much more efficient than small or light ones. The shape of the plane also greatly affects the amount of energy transferred from the wind to the plane, more especially where the plane is much inclined to the direction of the wind. Prof. Langley has also pointed out that the *power expended during flight decreases as the speed increases*, which is surely a revelation, and appears paradoxical, as was pointed out in the paper. His experiments also furnish data by which we can show the strikingly analogous action exerted by planes on water and air, respectively.

The pressure on a plane disposed at right angles to the current is obtained theoretically by assuming it produced by the destruction of the momentum contained in the mass of fluid that would, if unhindered, pass through the boundaries of that plane per second.

$$P = mv = \frac{Wv}{g} = \frac{Av}{V} \cdot \frac{v}{g}$$

$$= \frac{Av}{\frac{RT}{p}} \cdot \frac{v}{g} = \frac{Ap}{gRT} \cdot v^2$$

When

P = pressure in pounds.
M = mass of air reacting.
W = weight " "
g = acceleration due to gravity.
V = volume of a pound of air.
T = absolute temperature of air.
p = barometric pressure reduced to pounds per square foot.
R = a constant for air.
A = area of plane.
v = velocity of current.

Assuming ordinary values for the quantities,

$A = 1$ sq. ft., $p = 14.7$ pds. per sq. in., $T = 62^\circ + 461^\circ$.
$g = 32.19$, $R = 53.2$.

We have

$$P = k \times 0.00235 v^2$$

when k is a correction co-efficient applied because the assumed conditions do not obtain exactly. From Langley's experiments on air we take the average result,

$$P=0.00153v^2$$

$$\text{and } k=\frac{153}{235}=0.615$$

which is practically the same co-efficient as that experimentally determined for water. Seeing that these results are so nearly identical for the two cases, let us consider the aeroplane as the vane of a turbine or centrifugal pump, and anticipate a like action of air on this surface as that of the water on the vane. The pressure acting on the surface depends upon the mass passing per second, and the angle through which its motion is deflected by the resisting surface. Since the aeroplane is stationed in an unlimited stream, the mass acting is governed by the size of the plane and the configuration of its boundary, while the effective pressure per unit of mass of fluid depends solely upon the angle of deflection ; the efficiency of the whole system of transmission of desirable pressure depends upon the shape, which should have a smooth curvature to avoid sudden changes of direction, because a fluid as mobile as air is easily thrown into energy-absorbing whirls.

This theory, however, when applied to air, may need essential modification, since air being perfectly elastic and easily compressible the effects of impact, instead of being harmful, as in the case of water, may, when properly applied to fitting apparatus, become of immense utility, and form an essential feature of the future flying machine.

In calling attention to the statements regarding the Maxim motor, it is clear that a mis-statement has crept in. The heat required to furnish 300 horse power per hour, assuming a thermodynamic efficiency of 15 per cent., and 42.5 thermal units per minute as the equivalent of one horse power, is

$$\frac{300\times 42.5\times 60}{0.15}=5{,}100{,}000, \; B.T.U.$$

The total heat above 32° F. of 1 pound of steam at 320 pounds gauge pressure is 1212.5 thermal units, and the heat supplied per hour is

$$1212.5\times 600=727{,}500 \; B.T.U.,$$

or only about 14 per cent. of the amount required to produce that power.

Further, also, 200 pounds of naphtha, assuming that 15,000 thermal units of heat are received by the water per pound of combustible consumed, would furnish only 59 per cent. of the heat required to produce the power.

Attention might also be directed to the marvellous inefficiency of the Maxim machine as a whole, only 80 out of a total output of 363 horse power being useful as a transporting agent—efficiency, 22 per cent.

Mr. Mitchell.—With reference to the point raised by Mr. Laschinger as to the six hundred pounds of water required by the Maxim boiler for an hour's run, I may say that the present wording was due to a misconception on my part. The statement should have read: "The motor requires 600 pounds of water and 200 pounds of naphtha for an ordinary run." As a matter of fact, the Maxim engine at 300 horse power is calculated to use some 5,000 pounds of water and 300 pounds of naphtha for one hour's run.

HIRN'S ANALYSIS OF HEAT DISTRIBUTION IN THE CYLINDER OF A STEAM ENGINE

Edgar J. Laschinger, B.A.Sc.

Watts' original improvement on the "atmospheric engine" of Newcomen consisted in condensing the working steam in a separate vessel, and not in the cylinder itself. He knew that a tremendous amount of heat was wasted by allowing steam from the boiler to enter the cylinder which had the moment before been chilled by a cold-water injection, this loss occurring at every stroke, and he, therefore, provided a separate condenser, and arranged a mechanism whereby a communication was opened with the cylinder during the return stroke of the piston. His other improvements of excluding the air from the upper end of the cylinder by covering it and introducing steam to force the piston down, making the cylinder double-acting, using the expansive power of steam, changing reciprocating into rotary motion, etc., all followed in quick succession.

G. A. Hirn* seems to have been the first one to call attention to the fact that the walls of the containing vessel, even though not in direct contact with the cold condensing water, exercised a very great influence upon the action of the steam in its passage through the cylinder. He made experiments on an actual engine, and the results calculated from data thus afforded showed that this action is inimical to conditions of economy; so he immediately set about to study more closely this phenomenon, in order to determine means of decreasing the loss. In this work, Hirn was assisted by Hallauer, Leloutre, and others, reports and discussions being published from time to time in the "Bulletin de la Societe industrielle de Mulhouse." Professor V. A. E. Dwelshauvers-Dery, of Liege University, investigated more fully this complex action of the steam, and deduced formulas, so that with data obtained from certain measurements the "heat exchanges" between the walls and the working fluid during a complete stroke of the piston could be traced. The attention of engineers and men of science was now strongly attracted to this subject, and much experimental work has since been done. Chief among those who have furnished important facts and additions are Prof. Zeuner,* Major English,† and Mr. Bryan Donkin.‡

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*Hirn's first publication of his theory appeared in 1855.

Without entering into speculations (which is beyond the province or scope of this paper), the action going on in the interior of the cylinder of an ordinary steam engine may be briefly described as follows:

Steam, saturated or slightly wet, is admitted at the beginning of the stroke into a space enclosed by metallic walls, a space that had the instant before contained vapor of a much lower pressure and temperature, the exhaust of the previous stroke; thus a part of the entering steam met by chilling surfaces is rapidly condensed, the water of condensation covering them as a film, or whirling about as mist with the eddying currents of steam. During all this time the walls have steadily abstracted heat from the steam.

Now, however, the admission valve closes, and as the piston travels forward the steam enclosed completely begins to expand, and as it expands its temperature rapidly falls with the decreasing pressure, so that the walls are now hotter than the fluid, consequently heat travels from them to the interior, the water on the surfaces evaporates, and this new-made steam does work by augmenting the pressure acting on the moving piston. During expansion, therefore, heat travels from the walls to the fluid.

Near the end of the stroke the exhaust valve opens, and the steam finds relief either to a condenser, a low-pressure cylinder, or to the open air, as the case may be. The steam escapes at a low pressure and temperature during the return stroke, and the walls, still being very hot, an energetic exchange of heat goes on, the water on these interior surfaces being converted into steam. During the process of exhaust, therefore, there is a serious waste of heat, because the steam made by the heat absorbed from the walls is incapable of performing any positive work on the piston.

When the exhaust valve closes near the end of the return stroke, the steam enclosed is compressed in the space behind the piston, and its temperature rises; during this operation, therefore, the walls, rendered cold by their long exposure to the exhaust, may receive heat from the steam, but, unless the compression is considerable, the exchange of heat in this case is very slight and of little account.

The end of the stroke is now reached, and on admission a new cycle of operations similar to the one just described begins again.

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* Zeuner's Thermodynamik.

† Transactions Institution of Mechanical Engineers, September, 1887.

‡ Transactions Institution of Civil Engineers, Vols XCVIII., C., and CXV.

Tracing now the effects of the exchanges of heat for one complete stroke: During admission, the pressure is practically that of the boiler steam, but owing to condensation due to the heating of the walls more steam enters than is necessary to do the work; while expansion is going on, part of the condensed steam is re-evaporated, and thus increases the pressure, doing work; during exhaust, all the heat contained in the water present at release, together with all the heat furnished by the walls to evaporate that water, is absolutely thrown away.

The steam engine is a prime mover, using heat as the available and convertible energy, and is now treated as a heat engine by all investigators. The true method of engine testing is by heat measurements, and since the cylinder is the only essential part of the machine, thermodynamically considered, attention confined to it alone includes all that is necessary for a perfect knowledge of its efficiency as a converter of heat energy. As a Hirn's analysis includes a knowledge of all the quantities necessary for a complete test, it has been very appropriately called by Gustav Schmidt, "The calorimetric method of engine testing."

The data to be obtained for such an investigation consists of:

(1) Measurement of steam supply and its quality, to obtain the total heat furnished; this includes steam used in the jackets, if there are any.

(2) A record of the cycle of operations going on inside the cylinder; obtained by taking the indicator diagram.

(3) Observations to determine the heat rejected; by measuring the condensing water used, observing its temperature before entering and on leaving the condenser, and taking the temperature of the condensed steam. The heat dissipated from the cylinder externally is included under the head of heat rejected. In an engine with steam jackets, this loss is obtained by observing the amount of condensation taking place in them when the engine is at rest.

In Fig. 1, which represents the indicator diagram, the events of the stroke are designated as

(0) Representing the point of admission.
(1) " " cut-off.
(2) " " release.
(3) " " compression.

and the parts of the stroke as

(*a*) representing the admission,
(*b*) " expansion.
(*c*) " exhaust.
(*d*) " compression.

p_0, p_1, p_2, p_3, represent the pressures of the steam at the points indicated.

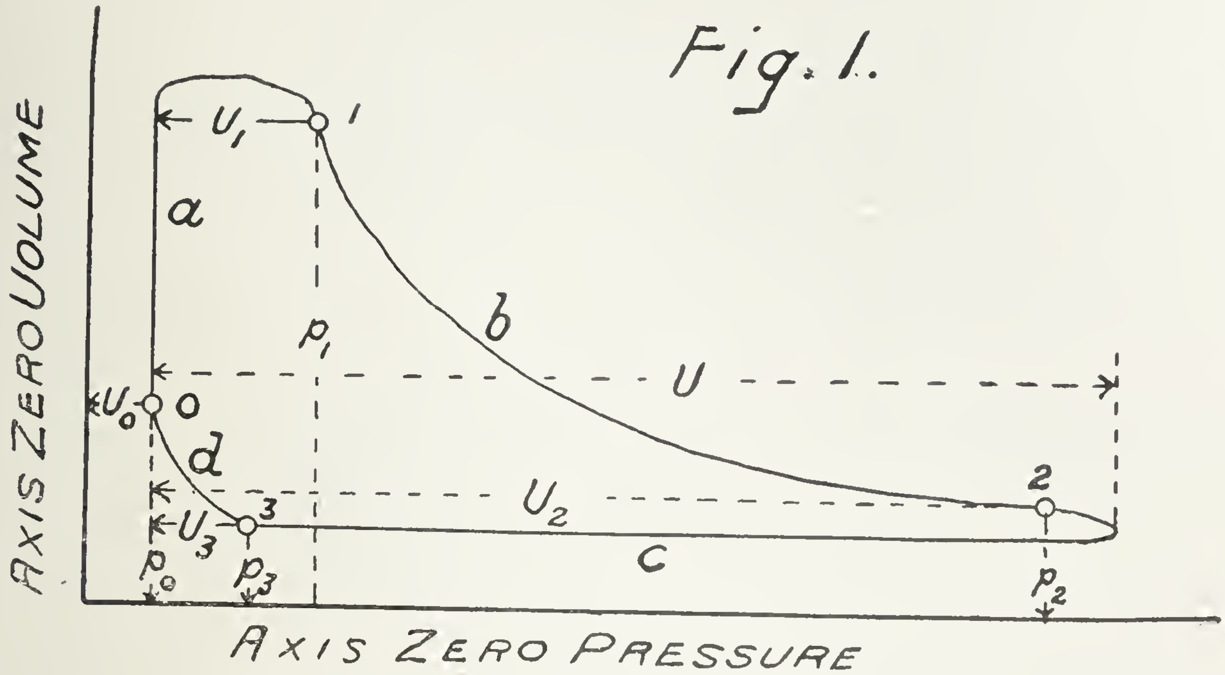
Fig. 1.

V_1, V_2, V_3, are the volumes of stroke behind the piston at the principal points in the cycle. Since there is no pre-admission shown on this diagram, the volume V_0, at admission, is identical with that of the clearance which is the space behind the piston when at the back end of its stroke.

Let W_a, W_b, W_c, W_d, be the absolute work done during the different parts of the stroke.

I_0, I_1, I_2, I_3, are the intrinsic energies of the fluid in the cylinder at the several points.

Now, let Q_a, Q_b, Q_c, Q_d, represent the heat exchanges between the working steam and the walls.

Applying the theory of the conservation of energy—

$$Q_a = I_0 + Q - I_1 - AW_a \qquad (1)$$

when Q is the total heat brought in by the working fluid and AW_a is the heat equivalent of the work done during admission, A being the reciprocal of the mechanical equivalent of heat.

$$Q_b = I_1 - I_2 - AW_b \qquad (2)$$

$$Q_c = I_2 + AW_c - Mq_4 - G\ (q_k - q_i) - I_3 \qquad (3)$$

when M is the weight of the working fluid, and q_4 its heat of liquid corresponding to t_4, the observed temperature of the condensed steam ; G is the weight of condensing water, and q_k, q_i, the heats of liquid corresponding to the temperatures t_k, t_i, of the water on leaving and entering.

$$Q_d = I_3 + AW_d - I_0. \qquad (4)$$

Now Q, the heat supplied by the working fluid, is found from the equation

$$Q = M\ (xr + q) \qquad (5)$$

when x is its quality, and r and q the heat of vaporization, and heat of liquid corresponding to its observed pressure p.

If the steam is superheated

$$Q = M\left[r + q + c_p(t_s - t)\right] \tag{6}$$

when t_s is the observed temperature, and t that corresponding to its pressure ; $c_p = 0.4805$ the specific heat of superheated steam.

Now $$I_0 = M_0(x_0 n_0 + q_0) \tag{7}$$
$$I_1 = (M + M_0)\ (x_1 n_1 + q_1) \tag{8}$$
$$I_2 = (M + M_0)\ (x_2 n_2 + q_2) \tag{9}$$
$$I_3 = M_0(x_3 n_3 + q_3) \tag{10}$$

where x with the reference subscripts represents the quality of the steam at the points, n refers to the internal heat of vaporization, and q the heat of liquid corresponding to the pressures as taken from the indicator diagrams. M_0 is the weight of steam compressed, which is not known.

We have also

$$V_0 = M_0(x_0 u_0 + v) \tag{11}$$
$$(V_0 + V_1) = (M + M_0)\ (x_1 u_1 + v) \tag{12}$$
$$(V_0 + V_2) = (M + M_0)\ (x_2 u_2 + v) \tag{13}$$
$$(V_0 + V_3) = M_0(x_3 u_3 + v) \tag{14}$$

u refers to the change of volume which one pound of water, volume v, undergoes when converted into saturated steam, volume s.

Now, since we have four equations and five unknowns, it is necessary to make an assumption in order to arrive at a result. For this purpose we may suppose, for the case of considerable compression at a low speed (a case rarely met with)

that $x_3 = 1$

$$\text{then } M_0 = \frac{V_3}{u_3 + v} = \frac{V_3}{s_3} \tag{16}$$

In other cases assume $x_0 = 1$

$$\text{then } M_0 = \frac{V_0}{u_0 + v} = \frac{V_0}{s_0} \tag{17}$$

$$\text{also } x_1 = \frac{V_0 + V_1}{(M + M_0)u_1} - \frac{v}{u_1} \tag{18}$$

$$x_2 = \frac{V_0 + V_2}{(M + M_0)u_2} - \frac{v}{u_2} \tag{19}$$

$$x_3 = \frac{V_0 + V_3}{M_0 u_3} - \frac{v}{u_3} \tag{20}$$

The intrinsic energies and the dependent quantities Q_a, Q_b, Q_c, Q_d, then become known. These are all assumed as positive in the equations, but if heat given by the steam to the walls is called positive heat furnished by them will be negative, and the quantities expressing that heat will appear in the result with a minus sign.

The only defect in this method of investigation as presented lies in assuming the steam dry, either at compression or admission. Observations, however, have shown that the assumption is practically true. Dwelshauvers-Dery calculates the heat rejected from the cylinder due to the action of the walls by making it equal to the internal heat of vaporization of the water in the cylinder at release,* thus assuming the steam caught at compression as dry; and he says that calculations thus based agree with actual measurements within the limits of experimental error.

As a check on the results, however, the following equations are applied

$$W = W_a + W_b - W_c - W_d \qquad (21)$$

where W is the indicated work

$$Q_e = Q_j + Q_a + Q_b + Q_c + Q_d \qquad (22)$$

$$Q_e = Q + Q_j - G(q_k - q_i) - Mq_4 - AW \qquad (23)$$

Q_e is the heat dissipated from the cylinder by external radiation, and Q_j is the heat furnished by the jackets.

By combining equations (3) and (23) we obtain

$$Q_c = I_2 - I_3 - Q - Q_j + Q_e + A(W + W_c) \qquad (24)$$

in which case the quantities depending on the condenser do not appear.

Since a graphical representation always gives a clearer view of the relative proportion of quantities than a mere statement, or an array of figures, Diagram No. 2 is drawn to show the results of a Hirn's analysis of the Brown engine in the School of Practical Science. The heat quantities are plotted as areas on equal bases, and their heights, therefore, represent their relative values. The engine is 50 horse power nominal, 12-inch cylinder, 30-inch stroke, 86 revolutions per minute. Fig. 3 is a copy of an average indicator card. Exhaust takes place practically at the end of the stroke, there is very little compression, and steam is cut off at 8 per cent. of stroke, the steam then being 32 per cent. wet, while at exhaust, owing to cylinder re-evaporation, there is present only 21 per cent. of moisture. Though the time of admission is so very short, still the heat lost by the entering steam is very great, showing how very rapid and energetic the interchange must be.

The item of chief interest is the heat rejected by the walls during exhaust, the magnitude of which Hirn proposed as a measure of the performance of an engine, but, as Prof. Peabody† points out, this is an unjustifiable use of that quantity.

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*Proceedings Institution of Civil Engineers, Vol. XCVIII., 1888-89.

†Thermodynamics of the Steam Engine, p. 192.

The hurtful influence exerted by the walls of the cylinder is due to the fact that they are of metal, which, being a good conductor of heat, the part in contact with the steam absorbs energy at the beginning, and parts with it during the latter part of the forward stroke, and all through the return stroke, thus acting simply as a vehicle of unconverted heat. A series of experiments carried on by Bryan Donkin, jr., show that only a certain depth of metal is affected, and for uncovered cast-iron walls one inch thick this "periodic portion" was found to be $\frac{2}{5}$ inch deep, steam being introduced at 48 pounds per square inch pressure, at 35 revolutions per minute. The outside metal remained at a constant temperature. When working condensing, there was a very slight increase in the depth the temperature fluctuations penetrated. Were it possible to have a cylinder and piston constructed of absolutely non-conducting materials, presumably there would be no initial condensation of steam.

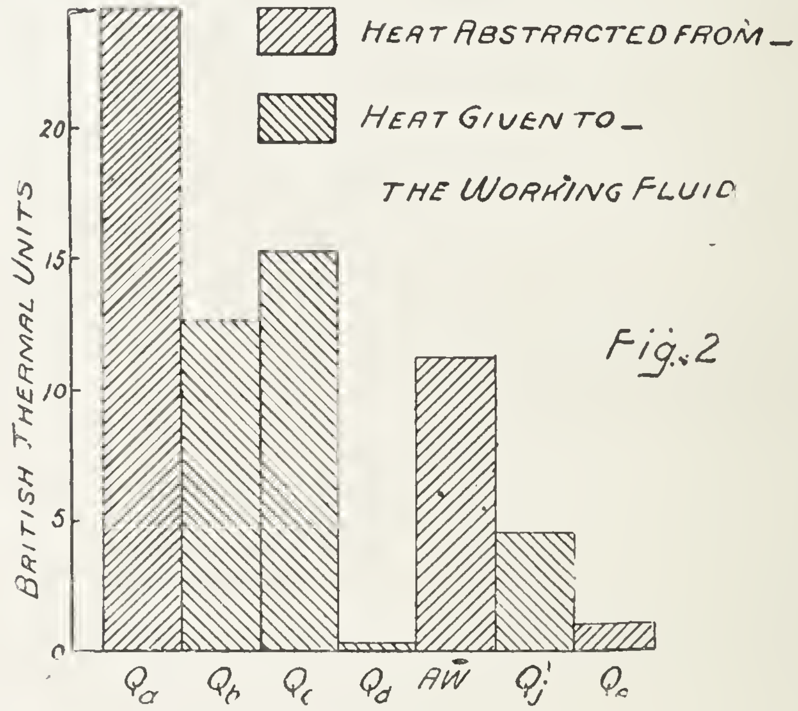

Fig. 2

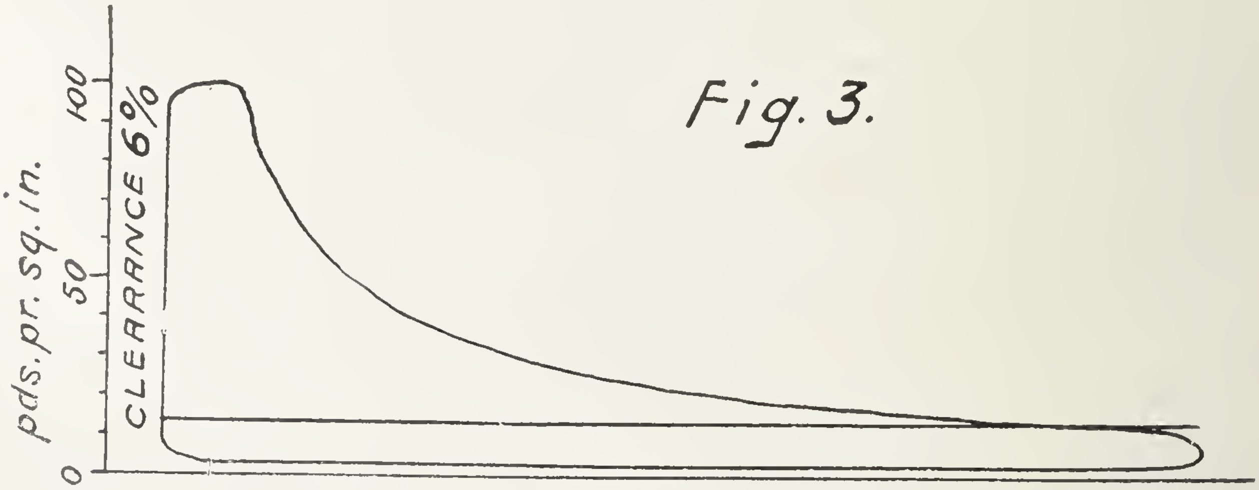

Fig. 3.

There are three methods of increasing the thermodynamic efficiency of an engine, in so far as it is affected by the material of the cylinder:

(1) By superheating the steam supplied.

(2) By jacketing the cylinder with steam.

(3) By increasing the rotative speed.

If the entering steam were sufficiently superheated, there would be no initial condensation, and therefore the steam being dry at release, "water, that powerful vehicle of heat," being absent, and dry gases (of which superheated or dry steam is a type) absorbing heat but very slowly and indifferently from heated surfaces, very little heat would be carried off.

Steam-jacketing induces a flow of heat from the outside to the interior of the cylinder walls, and decreases the thickness of the periodic portion, consequently there is less initial condensation, and, if sufficient heat penetrated, the interior surfaces would be dry at release, and practically no heat would be rejected by them during exhaust.

Since the heat absorbed by a body varies with the time of contact with the source of heat, it is plain that the shorter the time of communication the less heat is transmitted, and the greater the speed the less the depth the temperature fluctuations will penetrate the walls, and the less heat exchanged. The walls may in this respect be looked upon as a kind of heat pendulum of ample capacity swinging between the limits of the temperatures of admission and exhaust. This pendulum takes a charge of heat from the entering steam, proportional somewhat to the time of contact, swings with its freight to the exhaust temperature, and discharges heat as long as it is allowed to remain in contact with the issuing steam. Mr. Willians* made many careful experiments which prove conclusively that, within the limits of his engine trials (maximum speed 400 revolutions per minute), economy resulted, and, according to Dwelshauvers-Dery's calculations on those tests, the heat exchanges were all greatly decreased with increased speeds.

Other considerations beside those of thermodynamics, however, limit the application of the methods of increasing economy just stated, but a statement and discussion of their practical value, more especially in the many specific and widely varying uses to which steam engines are put, is waived in this presentation.

Engineering Laboratory, School of Practical Science,
Toronto, Jan. 24th, 1895.

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* Proceedings Institution Civil Engineers, Vol. XCIII., 1888.

THE VENTILATION OF SEWERS

By W. F. Van Buskirk, A.M. Can. Soc. C.E.

Sewer ventilation has received much attention in many works on sanitary engineering; therefore I do not propose going into an extensive history of the subject, nor to weary you with a long list of chemical smells. Smells may be very nice in the laboratory, but I must confess that I do not appreciate them in a sewer, and generally keep out of their sphere of influence as much as possible.

Were it possible to put in house connections, plumbing, and fixtures that would remove the household wastes, and at the same time prevent admission to the house of any gases or contaminated air from the sewers, the necessity for ventilation would not exist, and the much-abused manhole grating would be banished from the streets. This is becoming recognized as an impossibility in practice, however, and the shallow **S** trap of the text-book, whose only fault was that it sometimes refused to swallow a dishcloth, is in danger of losing its reputation as a defender of the household. It will, no doubt, be some little time yet before our old friend is returned to its proper station in society. It was only the other day that I discovered a touching example of architectural faith in the old S trap. Cellar drains with gratings in floor at upper ends were shown on plans as discharging into house drain on sewer side of cut-off trap.

The best modern practice aims at making sewers so perfect in alignment and grade that sewage will be kept moving at a nearly uniform rate of flow from the house drain to the main outlet, without depositing solids in any part of the system, and will reach the outlet before decomposition sets in.

Owing, however, to the impossibility of making perfectly smooth joints, etc., and of maintaining a uniform depth of flow at all times, a certain amount of the solids in suspension will be deposited in the system; and when decomposed or partially dried upon the walls of pipes will form gases, and impregnate the air with bacteria.

To mitigate this evil, flushing at frequent intervals and the admission of large quantities of fresh air to the sewers must be resorted to.

Automatic flush tanks located at the heads of all branch sewers liberate large volumes of water at once, filling or nearly filling the smaller-sized sewers and scouring the walls and bottoms of pipes. The air in front of these volumes of water is, of course, forced out at manholes, etc., and fresh air is drawn in through all openings both in main sewers and house systems immediately in rear of them. It will be seen, therefore, that unless fresh-air inlets are provided on sewer side of cut-off traps on house drains, the seals of traps will be broken, and a clear way will be provided for foul air and bacteria from street mains to interior of houses.

Exactly similar action takes place in each house system whenever a large quantity of water is discharged from a fixture, so that it is necessary to provide ventilators for the admission of air upon the sewer side of all traps in use. These ventilators should all be carried above roof line, since they will both admit and discharge air with every change in density of air in pipe system. Manholes with perforated covers will, if built at short intervals on line of sewer, admit and discharge a sufficient amount of air for ventilating purposes; and as they are generally located in the centre of streets at intersections are far enough removed from dwellings to prevent any injurious contamination of air.

It is important that any deposit on the walls of sewers be not allowed to dry before removal by flushing, for the reason that the number of bacteria and their spores that can be taken up by air from dried sewage is much greater than that from sewage in the liquid state.

In order to prevent deposits becoming at all dry, flush tanks should be timed to discharge after the period of maximum daily flow, since it is not advisable, owing to the large quantity of water required, to discharge them more frequently than once in twenty-four hours.

I am aware that my contention in regard to the danger of disease germs being carried by sewer air is at variance with the opinions of many engineers; but, on the other hand, I am supported by the great mass of the medical profession, whose opinions are worthy of consideration, although they are much inclined to blame "sewer gas" for "all the ills that flesh is heir to." In the discussion of this question, engineers generally have in mind sewers of the most approved construction, accurate grades and alignment, smooth walls, etc.; while doctors have in mind the sewer as it unfortunately is in many cases. As an example of the article which the doctor has in mind, I quote the description of a sewer recently examined by me:—

"A badly-constructed, foul-smelling stone box drain, located below the centre of the roadway, and having its outlet in the heart of the business part of the town.

"The box drain is constructed of stone, with open joints, has rough flag top and bottom, is two feet wide, and two and one-half feet deep, but is now nearly half filled with gravel and dirt. This drain is connected directly to cellars, sinks, etc., without traps, and has no openings for ventilation, and is never flushed except by heavy rainfalls."

Another, not in the same town:—"A ten by twelve box, made of two inch oak plank, no bottom; side planks kept in place by means of short lengths of two-by-four plank nailed to lower edges. This sewer is connected to wooden box street gullies without traps, and to many cellars, water closets, and sinks."

Who will say that disease germs cannot escape from these "sewers"? Our friends, the physicians, have many cases on record in their numerous periodicals and reports which, upon examination, will convince almost any one that diseases are communicated by sewer air.

The want of a reasonable explanation as to the manner in which the organisms are carried from one point to another has been the stumbling-block in the way of engineers. The recent experiments with the bacilli of typhoid fever performed by David Arthur, M.D., King's College, London, will, I think, go far towards removing this block. After describing several experiments in a report to the recent sanitary congress, he says:—"This, in my opinion, is one of the principal ways sewage microbes find access to sewer air. The bacteria of the sewage may creep like those of typhoid up the walls of the damp nutrient sewers, so that they may be literally alive with them. Moulds here also grow with great proliferation. In their struggle for existence they will often be covered with bacteria, and in shooting forth their spore stalks must carry some bacteria with them. When the spore stalks are sufficiently long to project from the damp sewer walls, and have become ripe for dissemination, the clinging bacteria and their spores will become liberated, mould spores and bacteria and their spores will be wafted with every air current; many will gravitate to the sewage, others will stick to the damp sewer walls, others will be carried up the ventilators to the outside air, while others, again, may gain access to dwelling houses."

I am strongly of opinion that all wastes known to contain germs of contagious or infectious diseases should be burned immediately, and should in no case be discharged into sewers.

This precaution will not, however, make it any the less necessary to attend to the proper cleansing of sewers, as it will be found impossible to destroy by fire more than a very small percentage of the disease germs ordinarily reaching the sewers.

Stratford, Ont., January 10, 1895.

DISCUSSION.

MR. W. L. INNES.—Recently a very important sanitary case was argued in Peterborough. The town wished to discharge its sewage into the Otonabee River, and the townships farther down the river objected.

Some of the greatest sanitary engineers, bacteriologists, and chemists of Canada and the United States gave evidence, and the question was thoroughly threshed out.

To me one of the most startling announcements was that "sewer gas is remarkably free from bacteria": that whatever other poisonous gases it contains, it is rarely a carrier of disease. I may have carried away an incorrect impression, but have simply stated what I believe was given in evidence before the court of arbitration.

THE CLEANING AND ANNEALING OF CASTINGS

H. L. McKinnon, '95.

The manufacture of iron is perhaps one of the simplest and oldest processes in existence, and yet the best grades of iron and steel in use at the present time require exceedingly great care and a thorough knowledge of the chemistry and metallurgy of iron and its ores in order to produce them.

History shows that for more than three thousand years human ingenuity has been at work on this metal, endeavoring to make it fill a place in the economy of man.

The first attempts were crude indeed. Imagine, if you can, a pit dug in some side hill and then fuel piled in and kindled, then ore and more fuel, and this kept up long enough to reduce the ore to a comparatively pure state; and, next, if you will go and examine some elaborately arranged smelting apparatus and compare the methods.

To examine into the reasons for these developments is scarcely within the scope of this paper, but I would like to drop a suggestion here, namely, that the luxuries of one generation become the necessities of the next. For example, in the early ages articles manufactured of iron were of necessity few, but as they became more common they might be regarded as essential.

While all men were only armed with bows and arrows a gun might be regarded as a luxury; but when one body of men came to battle armed with guns and protected with coats of mail and iron helmets, and met others who were still only provided with their bows and arrows, these latter might well consider that the guns and coats of mail were necessities which they could no longer afford to do without. Thus we see that as time rolls on new uses are found for this, the most useful of all the metals, and as a natural sequence it rapidly rises into commercial importance.

Iron is, with the probable exception of aluminium, the most widely distributed of all the metals. It occurs in a great variety of forms known as its ores, which contain, besides iron, quantities of oxygen, carbon, silicon, phosphorus, manganese, and sulphur, along with many other substances. The separation of iron from its impurities is accomplished by the process known as smelting, which consists essentially in roasting the iron in a stream of air or oxygen.

The immediate product of the smelting furnace is known as pig iron, and the particular brand of pig designates generally the proportions in which carbon, silicon, etc., are contained in it.

From various mixtures of the brands, all the cast iron in use is made by the process known as casting, with which we are all more or less familiar.

It is to the treatment of gray and white iron castings, between the time of casting and the time at which they are ready for use, that I wish to call your attention this afternoon. It has occurred to me that the processes used to change both the physical and chemical properties of iron castings would be of interest to engineering students. Many foundries simply brush the dirt from their castings, chip off fins and sprues, and then they are ready for use. For many purposes, and, in fact, for the greater part of the castings made, that is all that is necessary, but for mechanical and other reasons the above process is far from producing the castings in the condition frequently required. In foundries doing small work, or on castings which require to be cut with machine tools, we find that the practice is becoming more prevalent of changing the character of such castings by processes known as pickling, annealing, and rolling. Such foundries should be provided with a cleaning room, which should contain a pickling vat, washing vat, rolls, and an annealing oven.

The pickling vat is made like an open-topped wooden tank, inclined a little toward an opening in one end. The sides and bottom are lined with sheet lead, in order that it may not be affected by the sulphuric acid. The process is simple, consisting of covering the castings with a dilute solution of sulphuric acid, and allowing it to act until the sand, dirt, etc., peels off quite readily. The acid is then drained off into another similar tank, from which it may be dipped and used over again. The castings are washed in water, so as to remove the acid and scale mentioned above, after which they are dried. Where I saw this process in operation, the solution was composed of about two parts of water to one of commercial acid. The action seems to be that the acid attacks the metals, and in taking it away loosens the sand, etc., which has been set in the outside of the casting. This process is always attended by the loss of the outside crust of the iron, but in many castings strength is a secondary matter, as compared with a smooth and clean surface. Again, the removal of the outside crust is of advantage in castings used in motors and dynamos, due to electrical and magnetic considerations. We may take it as a general principle that soft iron is more suitable for electro-magnets than hard iron, so that by removing the hard crust we decrease the magnetic resistance.

The rolling process is one much used to give a smooth finish to castings. The most common method is to put the castings in metal cylinders, or barrels, of various sizes, commonly from three to four feet in length, and from eighteen to thirty-six inches in diameter, along with some chippings, sprues, and small scraps. The barrels are filled a little more than half full, and rotated at a moderate speed, about from twenty to fifty revolutions to the minute, the speed depending on the weight of the castings and on the size of the rolls.

Several kinds of rolls are used, those which I had the privilege of examining being made as follows: Two circular cast-iron heads were mounted on a shaft about two inches in diameter. At the outside of each of these there was a flange extending all the way round, and in these flanges bolt holes at regular intervals around the circumference. The sides of the rolls consisted of cast-iron staves about three or four inches wide, which were fastened to the heads by means of bolts passing through the flanges.

Emery powder and sawdust are materials sometimes used in rolls, the first to help wear away the surface, and the latter to prevent castings from wearing rapidly away or striking each other heavily.

Some of late have turned their attention to water-tight rolls. These have also metal cylinders, the main difference between them and the other style being that these will hold water. The cylinders are nearly filled with castings, and the rolls are then filled with water and rotated in a manner similar to the others. It is claimed that finer work can be obtained in this way, and as there does not seem to be any great difficulty in making rolls of this kind it would seem reasonable to suppose that in many cases the old-fashioned rolls would be displaced by water-tight rolls.

Annealing is the name given to the process of softening castings by heating them to cherry redness in a tight oven and keeping them hot for a period ranging from twenty-four to one hundred and twenty hours, then allowing them to cool slowly. Though the process is much the same for

Fig. 1

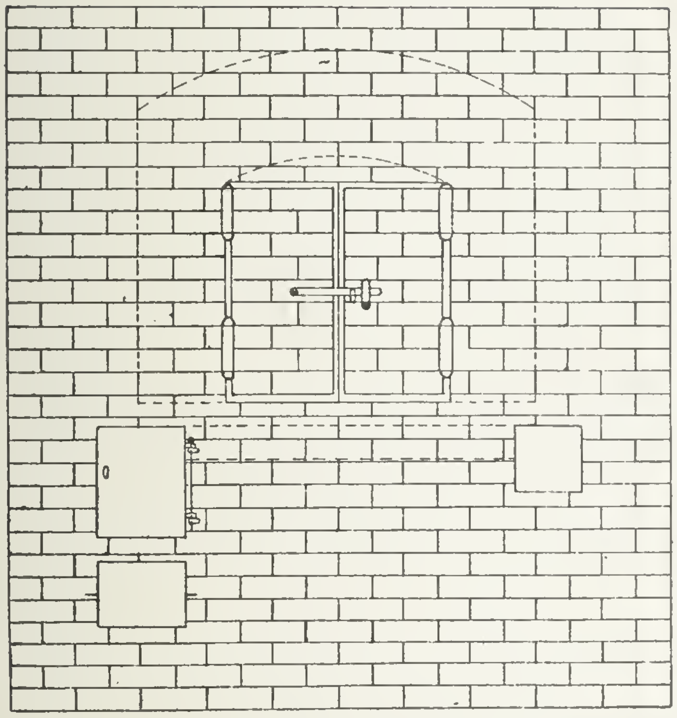


Fig 2

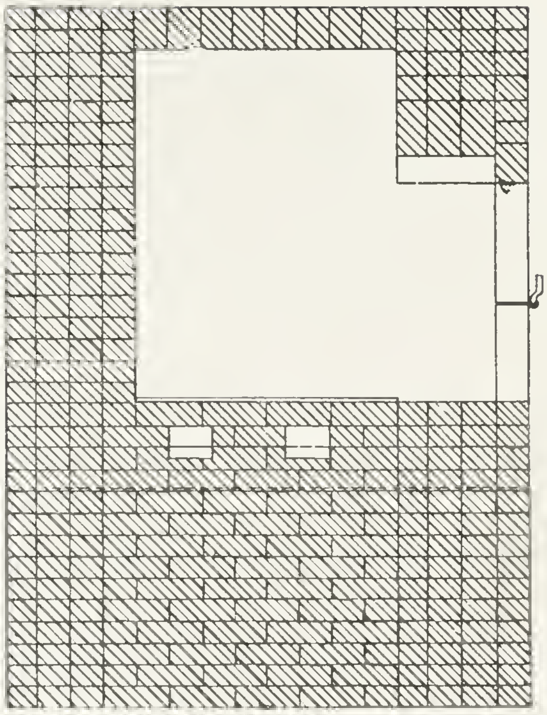
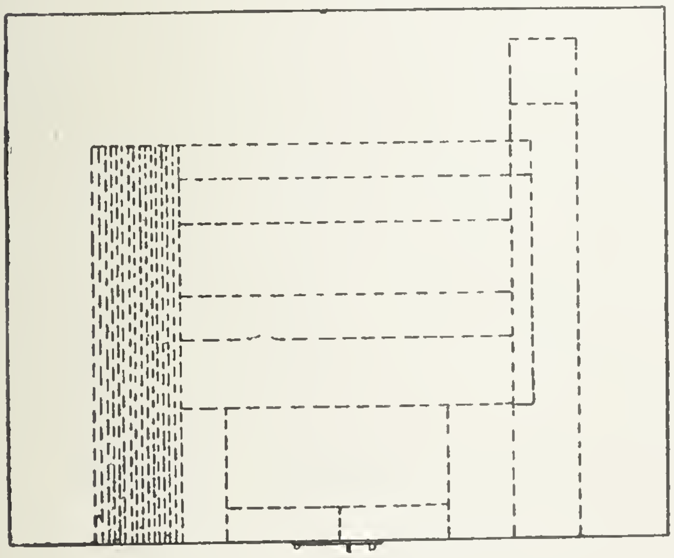


Fig. 3



ANNEALING
OVEN

all castings, we will consider the treatment of gray and white castings separately.

The oven in which the castings are heated will here be described. I have seen but one, which is shown in the drawings Figs. 1, 2, and 3. This oven worked satisfactorily, and for this reason I have thought it advisable to take it as a type.

It is built of hard white brick, and is as far as possible solid, which gives it great stability and strength. It will be easily seen that strength and thickness of walls are very necessary on account of the long-continued heat to which the walls are exposed. To further increase its strength iron rods run across it, one on either side, which may be screwed up, the stress, by means of long washers, being spread over a considerable area of brickwork.

The outside measurements of the structure are six feet by seven feet six inches, and eight feet high. The door to the oven consists of two pieces, each fifteen by thirty inches, and is built of brick, inside a cast-iron frame. The main frame to which these doors are hinged is also of cast iron.

The inside dimensions of the oven proper are three feet by four feet six inches, the height varying from three feet four inches at the sides to four feet in the centre, on account of the arched top which supports the brickwork directly above the oven. The fire grate is shown at the left in Fig. 3; and Fig. 1 shows the door to the firebox, which is twelve by fifteen inches. Beneath the grate is shown the ashpan, and a damper to regulate the draft. This draft is quite indirect, the products of combustion being led from the fireplace by means of two flues which are built in the brickwork, three inches below the oven. These flues lead to a larger one, which is at right angles to both, and which runs into the chimney at the corner of the structure. On the brickwork bottom of the oven is placed a cast-iron bed with raised flanges crossing it in two directions, and dividing it up into hollow squares, of five inches a side. The thickness of metal throughout this piece is three-quarters of an inch, and the depth of the hollow squares a little more than one inch.

The gray castings to be annealed are, if small, put into wrought-iron pots, often rectangular in form, and of convenient size to be easily handled in placing in the oven and removing again, and are covered with sand, so as to exclude the air as much as possible, and also to prevent the castings from uniting with each other, while raised to the high temperature of from 700° to 800° C. It is usual to fill these pots first and to place them in the oven, where they will be exposed to less heat than the larger pieces, these being thrown in together, and covered with sand. When all the castings that are to be annealed at one time are placed in the oven, the doors are closed up and all joints are daubed with fire-clay, or sometimes with common clay.

The fire is now kindled, and in the oven described wood is always used, which seems to give better satisfaction than other fuels, since the flame enters the cross flues better, and gives out its heat to better advantage. Thus a continually increasing temperature is obtained in the oven until the desired temperature is reached, when the fire may be slackened, and a constant temperature kept up for any length of time. In the present case that period is usually about twenty-four hours, after which the firing ceases and the temperature is allowed to gradually fall until cool, when the oven is opened and the castings removed. These castings will then be much softer than before the treatment, especially on the outside, and the tensile strength is generally somewhat increased, and the brittleness modified.

The process as applied to white iron castings is very similar, except that in place of surrounding the castings with sand they are surrounded by iron rust, hammer scale, or some substance rich in the oxides of iron. The length of time during which the heat is kept up is also increased, sometimes being as much as four or five days. In this case the annealing has a much more marked effect than on gray iron, as it seems to completely change the properties of the iron. From being the hardest and most brittle of all castings, they are transformed into those so tenacious and ductile that they may be bent and hammered when cold without fracture. The temperature at which such castings are fusible is considerably increased, and when fused they do not possess fluidity in any marked degree, but form a sort of pasty mass. They can with difficulty be welded.

The changes that take place during the process do not appear to be very well known, and are no doubt partly physical and partly chemical. The molecular structure may be affected by the heating followed by slow cooling, just as, for example, the different amorphous forms of sulphur are derived by heating to various temperatures, and then cooling by certain well-known methods.

White cast iron, according to many authorities, amongst whom might be mentioned Roscoe, differs from gray cast iron chiefly in the way in which the carbon is contained in it. Most of the books which I have seen state that in the white iron the carbon is combined feebly with the iron, forming the carbide of iron, while in the gray iron the carbon is uncombined and is in the form of graphite. Turner, of Birmingham, writing in the "Dictionary of Applied Chemistry," disputes the above, however, and from this we are led to infer that this is an open question at the present time.

Mallet doubts whether decarbonization is the cause of softening, and states that by annealing white brittle cast iron in either hæmatite, chalk, or sand we obtain not so much a chemical change as a molecular change of the constituent parts.

If, as a number of writers assert, the carbon is combined with the iron in the carbide, it is possible that the following reaction takes place: $2Fe_4C + O_2 = {}^2Fe_4 + 2CO$, after which the CO burns away, the oxygen for this reaction being obtained from the oxides in which the castings are buried. In the case of the gray iron castings, it is hardly possible that the silicate will be broken up while the temperature is kept so low as red heat. It seems, therefore, more likely that the change in this case is of a physical nature, although it is possible that a silicate of iron is formed near the surface.

We know that wrought iron, which is iron in its softest form, contains a very low percentage of carbon, probably less than one-half of one per cent., and the various pig irons used in casting from three to six per cent., which naturally would lead us to believe that when iron is softened the carbon is reduced.

The order in which these processes are performed is not that in which they have been treated in this paper. Annealing is usually the first, which is followed by pickling, if that process is used, but as it materially increases the cost a great many of the castings are taken direct from the annealing oven, and treated in the rolls. If the castings are pickled, that precedes the tumbling in the rolls, or rattle barrels, as they are sometimes called.

It should be understood that castings treated by the above methods are only used where their extra usefulness counterbalances their increased cost. For instance, in sewing machine work, where there is a good deal of milling to be done, it is very important that the iron be soft, and all castings for such uses require also to be very smooth. Many points must, therefore, be considered before we can say whether or not these processes are profitable. Malleable castings are usually made to obtain greater strength than is possible from common gray iron castings, and where the shape desired is difficult to forge from wrought iron or steel.

Toronto, Nov. 19th, 1894.

THE CANADIAN DAWN ANIMAL

A. T. Tye, '95.

Eozoon Canadense, the Canadian Dawn Animal, is essentially one of the most ancient fossils with which the palæontologist has to do, and should Eozoon actually be what some claim it is, namely, a foraminifer, the primordial fossils which once demanded reverence as the hoary monuments of an immense antiquity become quite youthful and modern in their altered aspect. The discussion which has arisen in regard to the animal nature of Eozoon has directed the attention towards Canada of a great many European scientists, whose papers are to a greater or less extent inaccessible to the general public. It is for this reason, therefore, that the writer has endeavored to give a brief but accurate description of this remarkable fossil, which is but too little known. The amount of literature upon this subject is extensive, and this description has therefore been given from the works of the two great authorities—Sir William Dawson, F.R.S., F.G.S., and Dr. Carpenter, C.B., F.R.S., F.G.S., etc., of London. The principal works from which authority has been derived are "The Dawn of Life," "The Microscope and Its Revelations," "Notes on Eozoon Canadense," and will be found very interesting to those who should care to enquire into that period when life was introduced. Before proceeding, however, we might quote the words of Professor Leconte, of California University: "It is in precisely such almost amorphous masses of protoplasmic matter that, according to the evolution hypothesis, the animal kingdom might be expected to originate."

EOZOON CANADENSE.

This remarkable fossil has been discovered in strata much older than the very earliest that were previously known to contain organic remains. It occurs in beds of serpentine limestone of the Laurentian formation, discovered by Sir William Logan. The Lewisian or Ottawa gneiss is the oldest known stratified rock in Canada, which is wanting in limestones and organic remains; even quartzites, slates, and dolomites are absent, such as would indicate the ordinary disintegration of rocks under water, or the evidence of any distinction of land and water; thus it is termed a fundamental rock, and "may be a portion of the original crust of the earth," formed before the causes of the ordinary deposition of sediment were called into play. Above this is what Dr. Sterry Hunt calls the Grenville series, and contains, besides large masses of gneiss, beds of limestone, diorite, pyroxene rock, quartzite and magnetite. The limestones, which are continuous, occur in three great principal bands, which are traceable for long distances. These bands are of great thickness, and consist of crystalline limestone with dolomite, and serpentine, graphite, apatite, and mica. In the Grenville band, which is uppermost, is found the most perfect Eozoon. Above the Grenville, again, is found the Upper Laurentian of Logan, which has afforded no fossils, and it is thought that part of it is of igneous origin and indicates great earth disturbances near the end of the Laurentian age. This disturbance was accompanied by a great lapse of time, and it is represented locally by schistose rocks.

PRESERVATION.

Now, as to the manner of the preservation of Eozoon, it is only necessary to work upon the supposition that it was a marine organism and many difficulties may be explained.

Large masses, usually of indeterminate form, are found in the above-mentioned beds which much resemble an ancient coral reef. These masses are formed of alternating layers of carbonate of lime and serpentine, frequently from fifty to one hundred in number. The great regularity in these alternations, and also the fact that it presents itself between other calcareous and siliceous minerals having caused suspicions that it was the product of an organic creature, very thin slices of the best preserved specimens were submitted to a rigid microscopic study by Dr. Dawson, of Montreal, who at once discerned the nature of a foraminifera. The *calcareous* layers had the characteristic appearances of a true *shell*, so arranged as to constitute an irregularly chambered structure, and frequently traversed by systems of ramifying canals corresponding to those of calcarina; whilst the *serpentinous* or other layers were regarded as the casts of that portion of the animal which the sarcode originally filled, caused by the infiltration of silicates. This action has occurred in various geological periods, and is going on at the present time, and is supported by an abundance of evidence.

Having taken up the investigation at the wish of Sir William Logan, Dr. Carpenter, of London, was not only able to confirm Dr. Dawson's conclusions, but to adduce new and important evidence in support of them.

The test or shell, which grew upon the floor of the ocean, was composed of a series of these calcareous laminæ, which, though not perfectly parallel, bent towards each other, forming flattened chambers, deeper near the bottom and becoming shallower in the upper parts, till at the top they become broken up into rounded cells, which constitute what is known as an "acervuline" mass. Now, when the chamberlets, which were formerly filled with the sarcodic matter of the animal, have become empty by reason of putrefaction, the space became filled with the infiltrations of mineral matter which were being deposited at the same time in the surrounding material. These minerals were especially pyroxene and serpentine. If well preserved, the calcareous laminæ are seen to be traversed with a multitude of canals, terminating in very fine tubuli. The usual form of Eozoon is that of a turbinate, or club shape, and these, by coalescence, form wide sheets or ununiform masses. In this case conical or cylindrical tubes or oscula may be observed to penetrate in the direction of their thickness. The sea-surface of these oscula is strengthened by the bending and coalescence of the laminæ. The walls of the animal have remained unchanged, except that they have become somewhat crystalline and assume the cleavage of calcite, which is common, however, in palæozoic shells and crenoids. Should the calcareous tests be broken up and scattered by the waves and currents, Dr. Dawson thinks that their fragments would consist of that which is found in the limestone, called archæospherinæ.

Assuming Eozoon to be a fossil animal of the above-described character, its mode of preservation in the ordinary serpentinous specimens is more simple than that of many fossils of later date. The chambers have been filled, and the canals and tubuli traversing the calcareous test have been injected with a hydrous silicate. This is a filling by no means infrequent in later fossils, and, as Dr. Carpenter has shown, it is going on in the modern oceans, in the case of foraminifera and other porous tests and shells injected with glauconite. Mineralization of this kind is not nearly so confusing as is the case of many fossil corals and fossil woods, the calcareous or woody matter being replaced by silica, oxide of iron, or pyrite. In a great many cases, in palæozoic fossils, the cavities have been filled with successive coats of different minerals, giving very complex appearances. That porous fossils, once infiltrated, are nearly indestructible should not be forgotten by the geologist. There is hardly anything, except fusion itself, that would cause the complete destruction of their structures, and these frequently remain in perfection even where the external forms have been totally lost. There is, therefore, nothing very strange in the preservation of Eozoon, except that it occurs in highly crystalline rock. But many palæozoic limestones are of a highly crystalline character, and yet retain abundant evidences of their organic origin; for example, the Chazy and Trenton limestones of Montreal have a perfectly crystalline fracture, yet, when sliced and studied under the microscope, they are seen to consist of organic fragments having their most minute structure preserved.

Many specimens of cœnostroma are found in the Silurian dolomite of Guelph, in Ontario, entirely replaced by perfectly crystalline dolomite, which not only shows the lamination, but even the fine canals. Corresponding appearances are found in the gray dolomite of Niagara. In places, stromatopora in masses can be seen dispersed through the rock in a similar manner to Eozoön in the Laurentian limestone. The mode of occurrence of these fossils resembles that of the Eozoon of Côte Ste. Pierre in every respect, except in the absence of hydrous silicates, and some of those who oppose the organic nature of Eozoon take the badly preserved examples of it as typical, and suppose that these are in the original mineral condition. Such a mode of argument would, however, dispose of all reasoning from the fossil structures, two of which are corals and woods. What seem to be a much more reasonable way would be to use the well-preserved specimens and portions as the means of interpreting the rest. Eozoon has, in common with other fossils, the independence of form, with reference to the mineral infiltration. This salient feature of the fossil attracted the notice of Sir William Logan, and caused him to believe in its organic nature long before its minute structure had been studied, and since then the argument has been much strengthened. The minerals, serpentine, pyroxene, and loganite, are found filling the chambers, while the first two, together with dolomite and calcite, fill the canals, which often have calcareous fillings in the finer ramifications when the main branches are filled with serpentine.

FORM OF EOZOON.

The shape of Eozoon in its general form is that of an immense confluent sheet or mass, which may be somewhat distorted by lateral pressure. But the fact has been established, from recent examples, that the normal shape of a young specimen is a broadly-turbinate, funnel-shaped, or top-shaped form, sometimes with a depression on the upper surface. These specimens also enable us to determine that there is no theca or outer coat, and that the laminæ pass outward without change to the margin of the form, where they seem to have a tendency to coalesce by bending. It is also evident, from the close study of sliced specimens, that there exist cylindrical depressions or tubes, sometimes filled with calcite or serpentine, crossing the laminæ vertically. These are noticed in the large confluent masses, and have no special arrangement, but their occurrence is by no means accidental, as they were designed for the admission of the sea into the lower portions of the structure. If Eozoon was an organism growing on the sea floor, it would be most probable that the waves would, in time, demolish the upper acervuline structure to some extent ; then the currents would distribute these particles over the sea bottom, and in time we would expect to find them imbedded along with Eozoon in the rock. In fact, such fragments are found in the Grenville band, the Adirondack Mountains, Mass., St John's, and in the Alps. The Redpath Museum (McGill College) has sawn slabs of limestone which show irregular layers or bands, and these are evidently successively deposited layers, and when examined closely show the structure of Eozoon.

VEINS OF CHRYSOTILE.

As has been mentioned, there are veins of fibrous chrysotile which abound in the serpentinous limestones of the Laurentian, but these are of secondary aqueous origin, as they fill cracks or fissures, not merely crossing the beds of limestone, but passing through masses of Eozoon, and the concretions of serpentine which occur in these beds. These chrysotile veins must, therefore, have had their origin long after the Eozoon was buried, as it even occurs after the beds have been folded and crumpled. They, therefore, have no connection with Eozoon, which has been subject to the same bending and compression as the rocks themselves. These veins have been mistaken by some for the very finely tubulated portion of the fossil.

OTHER LAURENTIAN FOSSILS.

In the Ottawa district specimens are found of peculiar cylindrical or elongated conical bodies, which are from one to two inches in diameter, and occurring in connection with beds or nodules of apatite. These are composed of a thick outside cylinder of granular, dark-colored pyroxene, with an inner core of white felspar, and show no structure, except, perhaps, that the outer cylinder is sometimes marked with radiating bands of a rusty color, which indicates the decay of radiating bands or plates of pyrite. These bodies may be organisms, perhaps, of the nature of archæocyathus, but this is only conjectural, and is based upon nothing of very positive importance.

CRYPTOZOUM.

Very large laminated forms, which have been described as Eozoon, have been discovered by Professor Hall in the Potsdam *(sandstones)* formation of New York, and in that of Minnesota. Professor Dawson discovered fragments of these fossils in the conglomerates of the Quebec group, associated with middle Cambrian fossils, and he states that whatever may be their zoological relations it is evident that their mode of occurrence in the Cambrian is similar to that of Eozoon in the Laurentian. There are also found in the Laurentian limestones peculiar laminated forms which, though often referred to Eozoon, have thin continuous laminæ, with porous spongy matter between, like cryptozoum or loftusia. It is not, of course, yet known whether these are distinct structures or peculiar forms of Eozoon. Such structures, perhaps, suggested to Mr. Julian his objection to the animal nature of the fossil. In the American Association in 1884, he suggested that the structure of this fossil might be due to the alternation of mineral matter in layers, formed in the passage-beds, between concretions and other mineral masses and their enclosing matrix. But in contradiction to this there is to be noticed: (1) Laminated passage rocks and laminated concretionary rocks have only simple laminæ, whereas Eozoon has connected or reticulated laminæ. (2) Laminated passage rocks have no structure other than crystalline. Eozoon has beautiful tubulations in the calcareous walls, besides tubes or oscula. (3) The mineralizing agent may be pyroxene, serpentine, loganite, dolomite, or mere earthy limestones. It is impossible that all these minerals should assume the same forms, etc.

LAURENTIAN APATITE AND GRAPHITE.

At Grenville and other places the Chazy formation contains many phosphatic nodules; these hold fragments of lingulæ, such as also occur in the surrounding beds. These nodules also contain grains of sand, and when heated emit an odor of ammonia. These are regarded by Sir William Logan and Dr. Sterry Hunt as coprolitic, and are said to consist of "a paste of commuted fragments of lingulæ, evidently the food of the animals from which the coprolites were derived." (Geology of Canada, p. 125.) It has been brought forward that these animals may have been some of the larger species of trilobites. In the Cambrian and lower Silurian rocks of Canada, phosphatic deposits occur in many localities, though they are not large enough to compete with the rich Laurentian beds. If, then, we agree with Sterry Hunt that the iron ores of the Laurentian are of organic origin, "the apatite which occurs in them may quite reasonably be supposed to be of the same character with the phosphatic matter which contaminates the fossiliferous iron ores of the Silurian and Devonian, and which is manifestly derived from the included organic remains. If we consider the evidence of Eozoon sufficient to establish the organic origin, in part at least, of the Laurentian limestones, we may suppose the disseminated crystals of apatite to represent coprolitic masses, or the débris of phosphatic shells and crusts, the structure of which may have been obliterated by concretionary action and metamorphism." Further, the presence of graphite together with the apatite in both cases is probably not accidental, but may depend in both on the association of carbonaceous organisms, vegetable or animal. This is strengthened by the presence of phosphatic shells in great abundance during the primordial age.

The Laurentian apatite nearly always contains a trace of calcium fluoride, which salt also occurs in bones, especially fossil bones. No organic remains have been found in the lowest part of the Laurentian, and these beds are also poor in phosphate. As has been already mentioned, Eozoon is most abundant in the Grenville band, and, likewise, the phosphates are found in the overlying beds.

Graphite. The graphite of the Laurentian in Canada occurs both in beds and in veins, and it is evident that its origin and deposition are contemporaneous with the containing rock. Dr. Hunt has concluded that there had been a Laurentian vegetation upon chemical grounds alone; Dana upon various grounds; and Dawson insisted, as early as 1860, upon the probability of the existence of some of the lower forms of plants. The quantity of graphite in the Laurentian is enormous. In Buckingham, in strata 600 feet thick, there is at least 30 feet of pure graphite. It may be said that the quantity of carbon in the Laurentian is equal to that in similar areas of the carboniferous system, and it may also be assumed, without much fear of contradiction, that in this age, and in those geological periods with whose organic remains we are most familiar, there is no other source of unoxidized carbon in rocks than that furnished by organic matter, and that this has obtained its carbon in the first instance from the deoxidation of carbonic acid by living plants. That graphite is found with organic limestones, beds of iron ore, and metallic sulphides, greatly strengthens the probability of its vegetable origin.

EOZOON AS A FORAMINIFER.

In the "Microscope and its Revelations," Dr. Carpenter, the eminent authority upon foraminifera, makes some interesting statements in regard to Eozoon. He states that although the animal nature of it has been called in question, on the ground that some resemblance to its supposed organic structure is presented by bodies of purely mineral origin (Professors Rowney and King), yet it has been accepted not only by most of those whose knowledge of foraminiferal structure gives weight to their judgment, but also by geologists who have specially studied the micro-mineralogical structure of the older metamorphic rocks—amongst the former the late Professor Max Schulze, and amongst the latter Professor Geikie, of Edinburgh, and Professor Bonney, of Cambridge and London. Whilst essentially belonging to the nummuline group, in virtue of the fine tubulation of the shelly layers forming the "proper wall" of its chambers, Eozoon is related to various modern types of foraminifera. It agrees with polytrema in its indeterminate zoophytic mode of growth; it resembles carpentaria in its incomplete separation of its chambers; in the calcarina it is closely resembled by the high development of the "intermediate skeleton" and of the "canal system." The succession of the calcareous layers one above the other resembles the stories of a house; while the chambers on each floor usually open into each other, like apartments *en suite*, but occasionally being divided by complete septa. These septa are traversed by passages of communication between the chambers which they separate, as stolons connecting the segments of the sarcode body.

Each layer of shell consists of two finely tubulated or "nummuline" laminæ, which form the boundaries of the chambers above and beneath, acting as the ceiling of one and floor of the other; and of a deposit between the boundaries of homogeneous shell, which is termed the "intermediate skeleton." The tubuli of the "nummuline layer" are usually filled (as in nummulites) by infiltration of mineral matter, so that in transparent sections they have a fibrous appearance, but fortunately it so happens that in some cases they have not been infiltrated, and the tubulation is as distinct as it is even in recent nummuline shells, having quite a resemblance in its waviness to the crab's claw. The "intermediate skeleton" is sometimes traversed by larger openings, which establish connections between the different layers of chambers; it is also pierced by aborescent systems of canals, which are often so extensively and minutely distributed through the structure as to occupy nearly all the space. These canals arise from irregular laminæ, or interspaces between the outside of the proper chamber walls and the "intermediate skeleton," as in calcarina, the sarcode body which filled them having been formed by the coalescence of the pseudopodial filaments passing though the tubuli. Not only the chambers in Eozoon are filled with siliceous infiltration, which takes the place of the original sarcode body, but even the very smallest of the canal ramifications are filled with it. This is found to be the exact state of things in the green sand of Ehrenberg, the Challenger collection, and modern foraminifera studied by such as Carpenter, Parker, and Rupert-Jones.

When we subject a piece of this fossil to the action of dilute acid, its calcareous portion is dissolved away, leaving an "internal cast" of its chambers and canal system, which, though dissimilar in arrangement, has its analogies in textularia, rotalia, and polystomella. The cast thus obtained of the chambers and canals is simply a model in hard serpentine of the soft sarcode body which originally filled these spaces, and extended itself into the minute ramifying canals of the calcareous shell; and, like that of polystromella, it affords an even more satisfactory elucidation of the relation of these parts than we could have gained from the examination of the living subject. In spaces between the layers of serpentine which were originally occupied by the calcareous shell, we see the "internal casts" of the branching canal system, which give the exact models of the extensions of the sarcode body. In specimens where the nummuline layer constituting the "proper wall" of the chambers was originally well preserved, that layer is represented by a thin white film covering the exposed surface of the segments. When this layer is studied with a sufficient magnifiying power, it seems that it consists of extremely minute needle-like fibres of serpentine, which sometimes stand upright parallel, and almost in contact, like the fibres of asbestos. Now, these fibres, which are less than $\frac{1}{10000}$ of an inch in diameter, are the internal casts of the tubule of the nummuline layer. Thus these delicate and beautiful siliceous fibres represent those pseudopodial threads of sarcode which formerly filled the minutely tubular walls of the chamber.

The change which is observed from the regular lamellæ to the acervuline is common with many foraminifera, an irregular grouping together of the chambers being frequently found in the later growth of types, whose earlier growth was of a much more regular system. In a quite recent specimen which has been discovered, it seems that each successive "story" of chambers was limited by the closing in of the shelly layers at its edges, such as to give the whole mass much the appearance of a straightened peneroplis. Thus, from a comparison with recent foraminifera, it appears that the only peculiarity of Eozoon lay in its indefinite extension, so that the product of a single germ might attain to the magnitude of a massive coral. This, it will be noted, is simply due to the fact that its increase by gemmation takes place "continuously"; the newer segments simply successively budding off and remaining in connection with the original stock, instead of detaching themselves from it as in foraminifera generally. Thus the little globigerina forms a shell, in which sixteen is the limit to the number of chambers, any above this detaching themselves and becoming independent, but by the repetition of this multiplication the sea bottom of large areas of the Atlantic ocean has become covered with accumulations of globigerina, which, if fossilized, would form beds of limestone not less massive than those whose origin was the Eozoon growth. The difference between the two may be compared in their mode of increase to the difference between a plant and a tree.

SUMMARY BY DR. DAWSON, LL.D., F.R.S., F.G.S., ETC.

1. Eozoon occurs in masses in limestone rocks, just as stromatoporæ occur in the paleozoic limestone.

2. While sometimes in confluent and shapeless sheets or masses, it is, when in small or limited individuals, found to assume a regular rounded, cylindrical, or, more frequently, broadly turbinate form.

3. Microscopically, it presents a regular lamination, the laminæ being confluent at intervals, so as to form a network in the transverse section. The laminæ have tuberculated surfaces, or casts of such tuberculated surfaces, giving an acervuline appearance to those laminæ which are supposed casts of chambers.

4. The original calcareous laminæ are traversed by systems of branching canals, now filled with various mineral substances, and in some places coarse and in many others becoming a fine tubulated wall. The typical form of these canals is cylindrical, but they are often flattened in the larger stems.

5. In some specimens, large vertical tubes or oscula may be seen to penetrate the mass.

6. On the sides of such tubes, and on the external surface, the laminæ subdivide and become confluent, forming a species of porous epidermal layer or theca.

7. Fragments of Eozoon are found forming layers in the limestone, showing that it was being broken up when the limestones were in process of deposition.

8. The great extent and regularity of the limestones show that they were of marine origin, and they contain graphite, apatite, and obscure organic (?) fragments other than Eozoon.

9. The specimens of Eozoon have been folded and faulted with the containing limestones, showing that they are not products of any subsequent segregation.

Books of reference for further information.

1. "The Dawn of Life," Sir J. William Dawson, LL.D., F.R.S., F.G S., etc.
2. "The Story of the Earth and Man," 1873.
3. "Geology of Canada," pp. 48-49. Sir W. E. Logan, LL.D., F.R.S., F.G.S.
4. "The Microscope and Revelation," W. B. Carpenter, C.B., M.D., LL.D., F.R.S., F.G.S., F.L.S., etc.
5. "Notes on Specimens," Peter Redpath Museum, McGill College. Sir J. W. Dawson, F.R.S., etc.

Toronto, Jan. 11, 1895.

DISCUSSION

Prof. A. P. Coleman.—This paper is a very interesting and suitable one, taking up a question which all Canadians should know something of. However, it presents only one side of the question, *i.e.*, the side of Sir Wm. Dawson and Dr. Carpenter. Most European geologists do not believe Eozoon was an animal, but hold the opinion, as do many American geologists, that it is of purely mineral origin. On the whole, the prevalent feeling of geologists is against the organic origin of the Eozoon Canadense. It would be well if some one would present the other side of the question.

Mr. A. T. Tye.—In reply to a letter to Sir Wm. Dawson, asking his opinion as to the animal nature of the Eozoon, I have received an answer from him, of which the following is an extract :

". . . . Zittel gives it (the Eozoon) a place in Volume I. of his 'Palæontologie,' although not definitely committing himself to it, and Carpenter, Parker, Rupert-Jones, Brady, Gumhel, Max Schulze, Reup, Hochitetter, and, in fact, all our best authorities on foraminiferal fossils, have accepted it.

"In this country I may mention Logan, Hunt, and Matthews, the principal opponents having been King, Rooney, and Mobius. As to the rank and file of geologists, not one in twenty has sufficient knowledge of fossil foraminifera and of the mode of preservation and microscopic examination in altered rocks to form an independent opinion, and they therefore follow authority as it appears more or less strong to them.

"I see that Gregory, of the British Museum, recently published a paper in the *Dublin Transactions* on some products of Mt. Vesuvius, which he compares to Eozoon. I have not yet seen the paper; but from what I learn, I believe the resemblance is merely accidental.

"I have no fear of the ultimate acceptance of Eozoon as a fossil, but at the present it labors under the disadvantage of lack of appreciative students, and of being isolated from the Canadian fauna. The new discoveries in Brittany and elsewhere are tending to fill the gap."

ON THE USE OF ASPHALTUM IN ENGINEERING CONSTRUCTION

FRANK N. SPELLER, B.A.SC.

HISTORICAL SKETCH.—The ancient historian, Herodotus,* in his description of the construction of the fortifications of Babylon, says that " When they had made a certain number of bricks they baked them in a kiln, then using boiling bitumen as mortar, and inserting mats of woven reeds between every thirtieth course of brick they built, first the borders of the moat, and next the wall itself in the same way." The remains of these works and many other vast structures have been uncovered and studied, but, owing to the inferior quality of much of their brickwork, many of these noble monuments have entirely disappeared, and no doubt those which remain to us owe a large part of their preservation to the bituminous cement with which they were built, which appears to be as good to-day as when laid over 3,000 years ago.

The former inhabitants of Chaldæa occupied a region of country about the Lower Euphrates, where very little stone or other natural building material was to be found, and, consequently they were forced to depend entirely on the manufacture of bricks for their building material. All the great structures in this country, of whose colossal size and grandeur history tells, and whose remains corroborate the tale, were constructed of these brick.

The bricks were of two kinds, baked and unbaked, the latter being invariably protected by the former, which were of excellent quality, and for this reason were always selected where extra strength was required.

The two cements in use as mortar in this district were stiff clay and bitumen, the former being chiefly used with unbaked bricks, while with the more durable form of brick, and in the more important parts of the structure, bitumen was prevalent.

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*I., 179.

The bitumen so frequently mentioned in ancient records as a cement is a natural asphaltum, obtained chiefly from Mesopotamia, where to-day springs are to be found, notably, at Hit, yielding a copious supply of maltha. As is usually the case in such regions, springs of crude petroleum are also found to some extent, and records exist to show that this was used, where found necessary, in the manufacture of asphaltic cement.

Among the ancient monarchies whose far-reaching influence centred in this district, in nearly every case we find the use of asphaltum to be characteristic of their civilization, although Assyria forms a notable exception in this regard, for, so far as is known, these people scarcely ever availed themselves of this resource so near at hand.

Besides as a mortar, bitumen was employed to prevent damp in floors, a very common form of pavement being one of baked brick imbedded in bitumen. On removing the débris from these floors, and taking up the large brick slabs, they are seen to be covered with inscriptions, the impression of which is seen to be accurately preserved in the bitumen when the brick is removed.

Another favorite use was in making concrete, which with them consisted of broken brick and asphaltic cement.

The above will suffice to give us an idea of the importance of this material at that time, and when we read of the palaces of Babylon, the hanging gardens and immense walls of that city, we must admit that they made good use of their resources.

Much of what has been said above might be repeated with regard to the ancient inhabitants of the southern part of our continent, the aborigines of California and Mexico, who applied the natural asphaltum found in such abundance in their country in building, in the manufacture and repair of domestic utensils, in weapons of war, in rendering their canoes water-tight, and in many other ways, as necessity and ingenuity suggested.

This will, perhaps, demonstrate that the application of asphaltum to engineering construction is not a new departure, but the revival of what is, perhaps, a long lost art, which has already laid the foundation for a great industry in our country.

It is with the object of setting forward the possibilities of this material, the peculiar properties which it possesses, and the manner and extent to which these properties have been taken advantage of so far by the engineer, that this paper is written.

In order to gather some idea of the value of asphalt as a cement in engineering work, it occurred to me to carry on a series of experiments to determine the adhesive and cohesive strength of this material, and to ascertain if in this way a practical test of the quality of an asphalt could be deduced, and, further, to investigate how the conditions under which the material was tested affected the results obtained.

The method chosen as being the most feasible and practical was somewhat similar to that used in determining the tensile strength of Portland cement. By selecting broken briquettes of the latter and cementing them together again with the asphalt to be tested, it was found that this material adhered to the Portland cement with great tenacity, and, as a rule, broke across itself with a clean fracture, providing, of course, that the Portland cement was sufficiently strong not to break of itself.

The difficulty found in obtaining a uniform quality of the necessary broken briquettes led to experiments in the use of brass or copper cast to the pattern of a Portland cement briquette cut in half. These were very carefully finished, to ensure an even bearing surface, but the ends to which the asphalt was intended to adhere were left rough, as cast, to give it a better hold.

This was a marked improvement, and gave more concordant results, when properly manipulated, which were also a little higher than those obtained with the former appliances. In most cases, especially where the tensile strength is high, the layer of cement, which should be not less than $\frac{1}{16}$ of an inch thick, breaks clean across itself; while if the cement be weak, it will partially or wholly pull away from the metal, leaving the latter with a clean surface. In this case the adhesion is less than the cohesion.

Most of the testing previously attempted in this line, so far as I have learned since starting these experiments over a year ago, consisted of attempts to mould the surface mixture of the asphalt pavement into briquettes while hot; this was subjected to a certain pressure, cooled, and broken in one of the standard testing machines. The proportions are generally within the following limits:

Asphaltic cement....................	12—16 per cent.
Limestone dust........................	10—15 "
Sand..................................	78—69 "

The results obtained by this method have not been very satisfactory, owing to the numerous varying conditions, such as the temperature, pressure, proportions of ingredients, etc., which affect the accuracy of the results. The result, of course, varies widely with the pressure employed, and, so far, it has been found impossible to attain the same degree of density in the laboratory as is obtained on the street, owing to the peculiar efficiency of the heavy steam roller in this regard.

The method of testing the cement *per se*, as first described, has been carried on in the city engineer's laboratory of this city for some time, and I think that this simplifies and brings the experiment within the limits of a practical test of some value, which may, when better understood, retain the same relation to asphalt and other bituminous cements as the tensile strength test does to Portland cement.

To get satisfactory results, certain precautions must be taken in melting the asphalt and in heating the metals before putting the briquette together. The metals are best warmed by placing them in water at about 150° F., and leaving them there until they are heated throughout. Meanwhile, the asphalt is warmed and melted in a suitable vessel, care being taken to bring it to a convenient state of liquid viscosity without overheating at any point. The metals are dried and quickly dipped into the melted asphalt, then stuck together, placed securely in position, and allowed to cool *slowly* to the temperature selected for breaking.

The testing is conveniently done on a Fairbanks' machine, the stress being applied by shot falling at a uniform rate. The uniform application of the stress at a certain standard rate is a necessity to reliable testing, and is automatically obtained in a simple manner with the Fairbanks machine, but with a little practice the Riehle machine may be made equally useful in this regard. The highest rate of application of stress which I have been able to get on the Fairbanks machine is 1,000 pounds per minute, which has been used throughout these experiments; it is two and a half times the standard rate adopted in the Portland cement tensile strength test.

The following are a few characteristic results collected as averages from a large number of experiments:

Refined Asphalt.	Tensile strength.*
"Land" quality	330 pds. per sq. inch.
Standard Lake	518 "
"Lake" (Series No. 15), at a temp. of 60° F.	460 "
"Lake" (Series No. 15), at a temp. of 71° F.	430 "
"Lake" (Series No. 21)	460 "
"Lake" (Series No. 14), good quality ..	525 "
Bermudez, at .. .. .. at 58° F.	330 "
Californian .. .. . at 40° F.	250 "

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* These figures are copied from the records in the books of the City Engineer's laboratory, with the permission of H. D. Ellis, Esq., Roadway Engineer.

It will be observed that the Trinidad asphalts give a much higher result than the purer varieties (Bermudez and Californian), although in each case the per cent. of bitumen petrolene is about equal, favoring the latter slightly. This apparent irregularity led to a question.

It has been stated that the adhesion of the asphalt to the metal is in nearly every case greater than the cohesion of the material in itself. This is a physical fact which may be demonstrated in regard to the adhesion of liquids and solids generally, and asphalt may be considered as a liquid, compared with the brass with which it is in contact. This led to the theory that the excess of fine inorganic matter * in the Trinidad asphalt (see analysis on page 11) brought into play this superior adhesive power possessed by the bitumen.

To test this the following experiment was arranged: the Californian asphalt above mentioned was taken, finely ground and mixed with kieselguhr—a very absorptive siliceous earth—the mixture having the proportions:

Bitumen	70.4	per cent.
Kieselguhr	25.1	"
Other inorganic matter	4.5	"

The organic matter non-bituminous was too small to be noticed.

The effect of this addition of mineral matter was to raise the breaking strength from 250 to 333 pounds per square inch; the material, however, partly pulled away from the metal, otherwise much higher results might be expected. Further experiments will be made soon, as this has opened up a very important field of research.

This points to the conclusion that the fine mineral matter is an advantage to the asphalt for certain purposes. I am not stating that the inorganic matter of the Trinidad asphalt is particularly advantageous, it is combined with too much organic matter and clay to be so; but may we not infer that the fine clean microscopic siliceous matter is a distinct advantage, and a thing to be provided, if possible artificially, when found wanting?

Where dealing with Trinidad asphalt alone, the tensile strength test affords us a ready means of comparison. A case in point is selected, a

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*This mineral matter appears, when all organic matter has been removed, as a reddish-brown impalpable powder, consisting of finely divided fragments of minerals, chiefly quartz mixed with a little clay. It is so intimately mixed with the bitumen as to almost form an integral part of the same.

few of the physical properties being added to further show the difference in nature of the asphalts. The "land" is evidently the least desirable.

	"Land"	"Lake"
Softens at	197° F.	178° F.
Flows at	230° F.	188° F.
Percentage of flow	32	100
Tensile strength	331	518 pds. per sq. in.

In dealing with refined Trinidad asphalts the temperature within ordinary limits has little effect on the results, especially the harder the asphalt becomes; this is illustrated in example, Series No. 15 above.

Another example is cited to show the ordinary degree of concordance to be expected between results obtained with the same material.

Refined lake asphalt on Riehle machine, temperature of test 65° F., tensile strength 520, 525, 540 pounds per square inch.

By obtaining cements of the same degree of penetration, made from different asphalts, it is easy, by following a course such as that outlined above for refined asphalt, to make a quick comparison of their strength; and, by varying the temperature, we get an idea of the variation of the strength with the temperature. As an example, the case of two cements of "lake" and "land" asphalts is selected, the penetrations being almost identical (60° and 56° respectively):

Temperature of Test.	"Lake."	"Land."
34° Fah.	450 pds. per sq. in.	395 pds. per sq. in.
57° "	368 "	310 "
68° "	215 "	215 "
78° "	182 "	182 "

As the figures are averages, and the "lake" cement of a rather inferior quality, this may account for the equivalence of the results for the two higher temperatures.

An attempt was made to compare Bermudez asphalt (an exceptionally pure variety from Venezuela, South America) with that from the "lake" in Trinidad. Two Bermudez cements were made in the laboratory. No. 1 contained 100 refined asphalt to 11 of oil; penetration, 87°. No. 2 contained 100 refined asphalt to 9 of oil, penetration, 71°.

A Trinidad lake cement of penetration 71° was used for comparison with No. 2 Bermudez, the average results being as follows:

Temperature.	Bermudez, No. 2.	Trinidad.
35° Fah.	430 pds. per sq. in.	468 pds. per sq. in.
55° "	325 "	309 "
64° "	270 "	253 "
68° "	157 "	212 "

As far as this test indicates, they seem to be on a par, although it must be remembered that the Bermudez cement is nearly pure bitumen, while the Trinidad contains about 30 per cent. inorganic mineral matter, besides far more residuum oil than is present in the former.

As an example of a "lake cement" of good quality, tested in this manner, the following will serve. Penetration, 80°.

Temperature.	Tensile strength.
35° Fah	477 pds. per sq. in.
40.5° "	400 "
50° "	298 "

As the temperature rises above 55°-60° the strength of the cement rapidly diminishes as the cement gets softer, and it becomes more difficult to get good results; therefore, it appears to be of more advantage to break the briquette below 50° Fah., this being easily attained by immersing the briquette in water of the desired temperature for fifteen minutes previous to breaking.

It may be premature at this stage to specify any standard, but, from a consideration of from 200 to 300 experiments made during the past year, it appears to me that a "lake asphalt cement" should (if the penetration is between 70°-80°) have a tensile strength, at 35° Fah., of over 450 pounds per square inch, and, at 50° Fah., at least 300 pounds per square inch, the experiments being made on a cross-section of at least one square inch, and with a rate of application of stress of 1,000 pounds per minute.*

Coal tar, and other products of destructive distillation of like nature, often have a tensile strength of 300-400 pounds per square inch at first, but are distinguished by generally diminishing in strength very rapidly when allowed to stand, especially when in water.

In considering this part of the subject, the nature of the material with which we are dealing must not be overlooked. It is not such a substance as iron, wood, or even Portland cement, which will withstand a stress of greater or less degree without yielding, for in the case of an asphaltic cement, although it may appear quite hard and brittle, yet it will always yield before even a slight stress continuously applied; therefore, while it is invaluable for certain purposes as a cement, yet its field of utility is limited, but nevertheless well defined. From this it will be seen how important the regulation of the rate of application of stress is in making experiments, and for this reason the above figures are necessarily somewhat arbitrary. However, they sufficiently illustrate the fact that asphalt and its products possess a wonderful degree of strength, combined with plasticity and absolute impermeability, which eminently fits them for certain important uses in engineering construction, a few of which will be briefly described.

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* The briquettes should be allowed to stand twenty-four hours after being made up, before breaking.

STREET PAVING.—In a paper which I had the honor to present before this Society last year on the subject of "Asphalt and Asphalt Paving," a brief history and outline of the industry was given. The facts in regard to the widespread and general popularity of this pavement are now better known, and it will, therefore, be unnecessary, even if we had the space, to give it more than a passing glance in this paper. Suffice it to say that in the short interval of twenty-five years, since this infant industry was first started on this continent, it has increased with such tremendous strides as now to employ millions of dollars of capital and a proportionate amount of skilled labor; and asphalt pavements have now been laid in ninety-two cities of this continent, requiring an average importation of 70,000 tons of asphaltum per annum from the island of Trinidad alone, to say nothing of the native material in use. The latest statistics, up to January 1st, 1894, show the total amount of asphalt paving in America up to that date as:

	Sq. yds.	Miles.
Trinidad asphalt	13,900,000	911
Asphaltic limestone	151,000	10
Asphaltic sandstone and other asphaltic materials.	619,000	41
	14,670,000	962

The total area of asphalt pavement laid in Europe up to the same date was 2,323,413 square yards, or 151 miles, over half of which is in Berlin.

The subject of asphalt paving is so extensive that a mere outline of the technology and laboratory testing in connection with this work would require a few articles to itself, so we will pass on to some of those uses of asphaltum in engineering works which, while valuable, are not as familiar as the asphalt pavement, of which we are being constantly reminded in the new beauty lent to those of our cities in which this pavement has gained prominence.

RESERVOIR LINING.—During the last few years much of the lining of reservoirs on this continent has been done with asphalt, by the recommendation of some of the most eminent American engineers, and the results are such as to encourage its continued use.

The peculiar nature of asphalt especially adapts it for this work, where strength, elasticity, and imperviousness to water are required; and in lining new embankments, where some settlement is to be feared which would be fatal to a concrete lining, the asphalt lining will, if properly laid, adapt itself to such changes in the foundation without injury. Nor is the ease with which this lining may be repaired an advantage to be overlooked, as new material may be made to unite perfectly with the old wherever a patch may be required.

To ensure a good, firm, and uniform foundation, the earth should be well rolled with a five-ton steam roller. The rolling of the slopes is accomplished by means of a heavy roller manipulated by a cable and drum connected with an engine on the bank, the whole being carried on a truck, which may be moved around the reservoir on a track of ten-foot gauge laid on the bank for this purpose.

In order to prevent dry earth from the slopes rolling down and mixing with the asphalt when being laid, it has been recommended that the surface of the slopes be covered with a layer of cement of lime and sand mortar, one-half to one inch thick, which, when dry, presents a clean and even surface for the laying of the asphalt lining.

The lining is best laid in three coats, consisting of a layer of asphaltic cement, one-quarter to one-eighth inch thick; on this is placed the body of the lining, which is a mixture of asphaltic cement and sand, the cement amounting to about 16 per cent., this layer being about one and a half inches thick when compressed; finally, a dressing of asphaltic cement is applied to the surface similar to the first layer.

To get an intelligent view of this matter, it will be necessary to discuss in brief the various kinds of asphalt on the market. These may divided into *two* classes, and the three most important examples which we have are:

(1) Trinidad asphalt.

(2) Bermudez asphalt, from Venezuela, S.A.; and California asphalt, from that state.

The first asphalt is well known in connection with street paving, to which it has proved itself to be well adapted.

On analysis,* an average example of refined Trinidad pitch lake asphalt will show :

Bitumen	Asphaltene	20.90 per cent.
	Petrolene	34.85 "
Inorganic matter		38.25 "
Organic matter (non-bituminous)		7.60 "

Nearly all "land" asphalt is of very much inferior quality to this, and should be guarded against. Although this asphalt has been so successful in street paving, yet the per cent. of bitumen is too low to make it desirable in works exposed constantly to water, the high per cent. of organic matter, other than bitumen, being also a disadvantage on the same account.

The second class of asphalts mentioned above are distinguished by their purity. This does not give them any advantage—so far as is known at the present time—over Trinidad asphalt in paving, but they are to be preferred and sought after for such work as reservoir lining. The following characteristic analyses speak for themselves :

			Bermudez.	Californian.
Bitumen	Asphaltene.	total bitumen	96.09 per cent.	29.73 per cent.
	Petrolene			61.46 "
Inorganic matter			2.76 "	5.79 "
Organic matter (non-bituminous)			1.15 "	2.49 "
			100.00	99.47

The Californian asphalt has been largely used, and is particularly valuable in this regard, as it is as good as any asphalt at present on the market, and, being mined in the country, is the cheapest, selling at $15 per ton of refined material at the refinery in California, although, in Toronto, it would cost $30 per ton, which is, however, still considerably below any other at our present scale of prices.

California also produces a natural asphaltic oil or maltha which dissolves the asphalt and forms the most efficient fluxing material known ; the objection to the residuum oil in general use in the east being that it does not dissolve the asphalt, but merely forms a mechanical mixture, which is also hard to make perfectly, owing to the great difference in specific gravity of the two ingredients.

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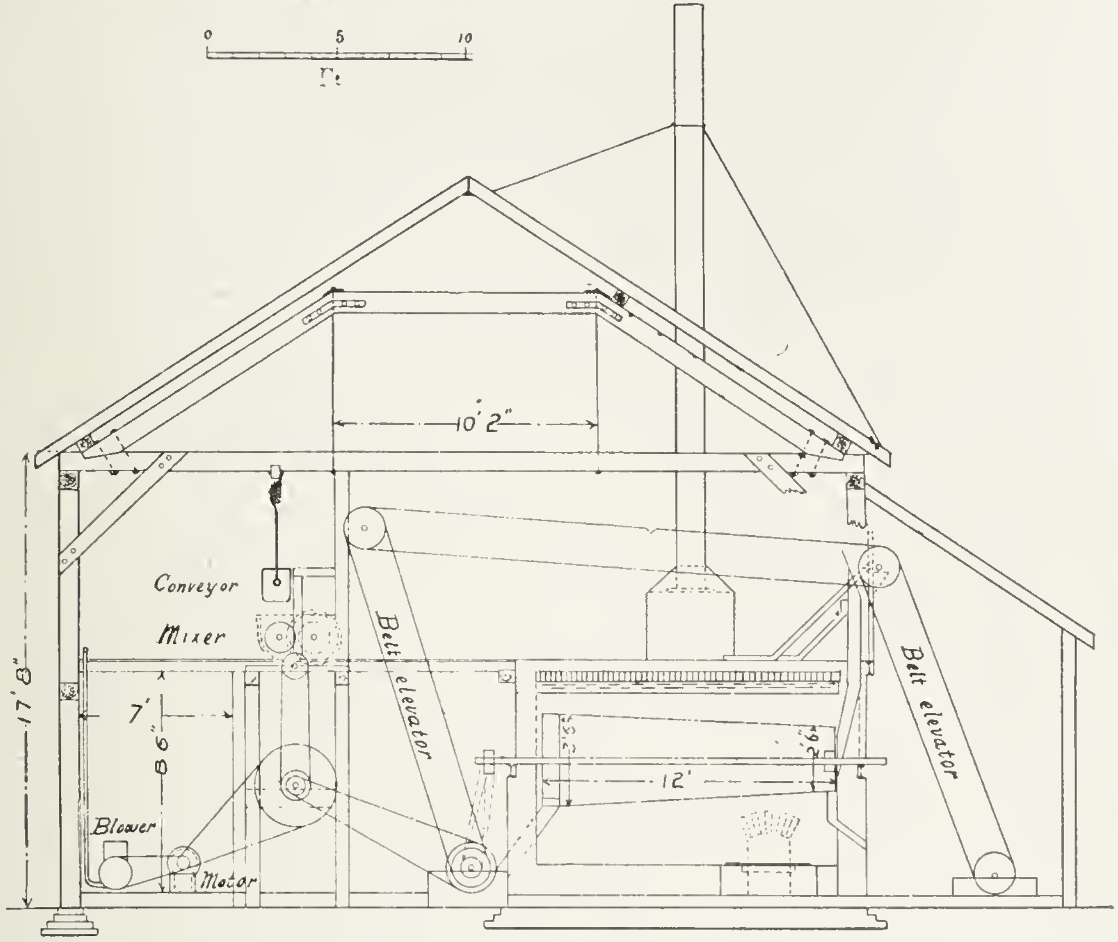
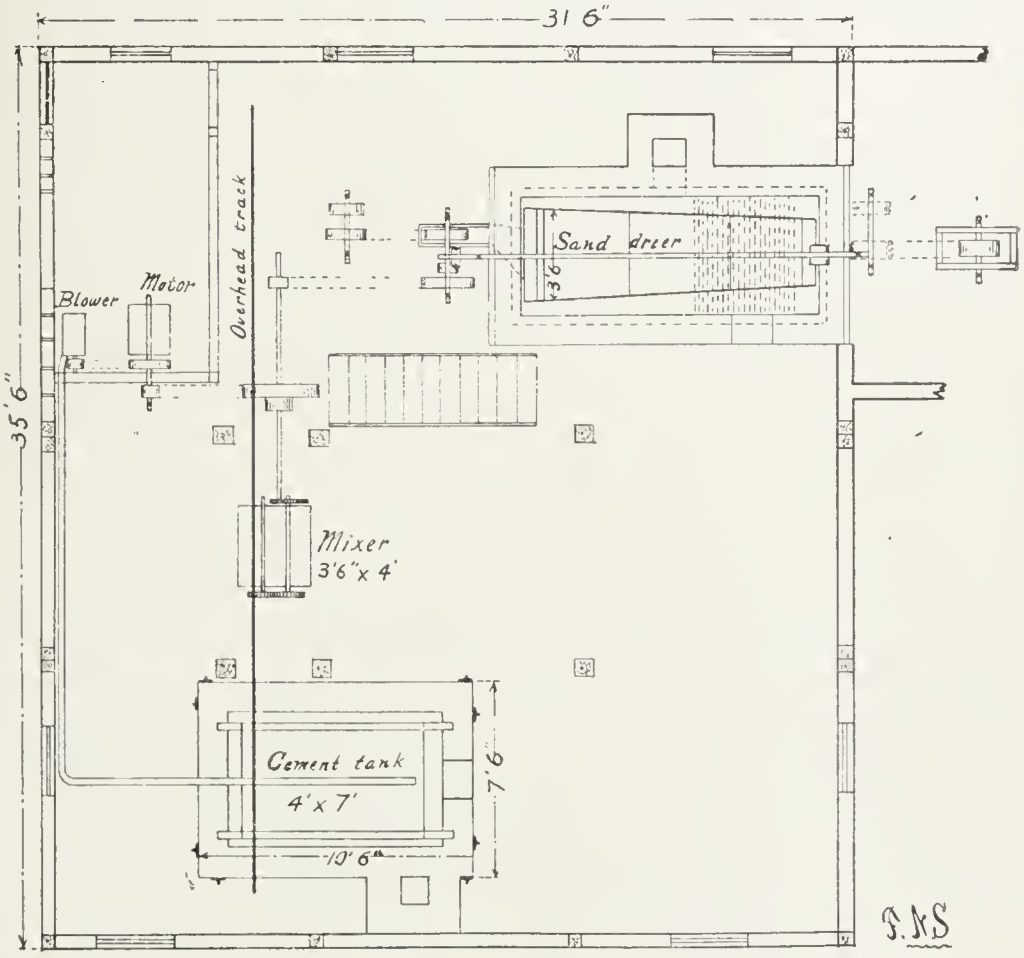
*All these analyses were made in the laboratory in connection with the City Engineer's Department of this city.

The plant in which the material is prepared for work is shown in the Plate, although for any extensive piece of work two or three kettles and as many sand drums would be necessary. The refined asphalt, which has been previously weighed, is placed in the cement tank, and the fluxing material (residuum oil or maltha) is added, preferably hot, until the proportion is arrived at which is most desirable for the work in hand. This must be varied with the circumstances and the object for which the cement is required. Thus in the case of our reservoir lining 15-18 per cent. by weight of fluxing material would be used for the cement in the second layer, while this proportion would be decreased for the final coat. The exact proportions, however, can only be fixed after an examination of the asphalt and oil in the laboratory. The bottom of the tank is protected against the direct action of the heat by a brick arch, the products of combustion being finally allowed to go around the tank before going up the flue. Agitation is provided by either direct mechanical means, as with paddles, or by means of compressed air escaping through a cast iron perforated pipe running along the bottom of the tank. The latter device is very satisfactory, for while it keeps up a thorough agitation the air escaping at the bottom of the tank helps to keep the contents from becoming unduly heated there, thus injuring the material. It has been objected to this method that the air may have a deteriorative effect on the asphalt by oxidizing the petrolene, but no fears need be entertained in this regard if the temperature does not rise above 325° F., and 300 degrees is quite enough for all ordinary conditions.

The preparation of the sand is next to be considered. In quality, it should be clean and free from all dirt. A considerable gradation in size is a desideratum, and if the sand does not contain 10 per cent. of fine, clean mineral matter, passing through a sieve of 100 meshes to the linear inch, this should be provided by substituting 10-15 per cent. of finely ground limestone for a part of the sand. The sand is raised by belt elevators, and dropped into the inclined revolving drums, in which it is dried. On coming out through a sieve of 10 meshes to the inch attached to the end of the drum to separate the large material it is elevated again to the mixing floor, where it should arrive at a temperature of 300° F. On this floor stands the mixer, a pug-mill with two horizontal shafts, to which are attached radiating blades, which work in and out among one another, producing a most thorough mixture. A conveyer running along an overhead track carries the sand (about 730 pounds) to the mixer, into which it is

ASPHALT REPAIRING PLANT





dumped. A similar vessel holding about 140 pounds of cement is run from the cement tank, and the cement is skilfully dumped into the mixer on top of the sand. In one and one-quarter to one and one-half minutes the mixing is completed, and by pulling a lever the sliding bottom is thrown back and the charge falls into the wagon waiting below. The above processes are similar to those in preparing the asphalt paving mixture, in which work the plant is fitted up with every convenience to facilitate the work and provide a large output in a short time. If an asphalt paving plant is available within two or three miles of the work, all the better; but, if not, a temporary plant may be cheaply rigged out, consisting of a mixer, two melting tanks, one or more sand driers, and a portable engine, to which the mixer and sand drums are geared. This will do the work in a satisfactory manner.

It is needless to point out that the most careful watch should be kept on all stages of the operation in the plant by some person thoroughly familiar with the technology of the subject. A laboratory for testing is an important adjunct to the plant, where systematic records of the work are prepared from tests made there. The consistency of the asphaltic cement may be controlled to a nicety by a liberal use of the penetration machine.

To proceed with the practical construction of the reservoir lining. The first layer of cement has been poured on and ironed with hot smoothing irons. On this the mixture above described is placed; this should not arrive on the site of the work with a temperature below 250° F., and it is a critical operation laying it with the temperature of the air below 45° F., as the material cools on the surface before sufficient compression can be applied. The work is carried on in strips 10 feet wide, the material being raked out, rolled with hot rollers, and then ironed as above, and finished with the steam roller where possible. Rows of anchor spikes (made of pieces of scrap iron 1″ x ⅛″ x 7″) are driven in at one-foot intervals through the warm material to bind it to the slope, each alternate spike being driven in flush with the surface, the others being left to support planks to enable the men to ascend to the work above. When the finishing coat of asphaltic cement is to be applied all remaining spikes are driven in, and any dirt which may have fallen on the surface is swept off. The cement is poured over the surface and well ironed into the layer underneath. When finished, this surface should present a bright glossy appearance, and be from one-eighth to one-quarter inch thick and of the consistency of leather. The cost of this lining depends largely on the situation in which the work is done, but should be between $1.00 and $1.25 per square yard.

If the soil contains water, this must be got rid of by suitable drainage, or it will seriously impede the progress of the work. A very ingenious method of removing this water is that devised by Mr. James D. Schuyler, M.Am. Soc. C.E., who has constructed a number of reservoir linings in this manner in the Western States; it consists in cutting deep drains as far up the slopes on both sides as any water is to be found, filling them with broken stones to a depth of one foot, and then covering with boards and filling up with earth again. These drains converge to wells in the bottom of the reservoir, in which sections of twelve-inch cast-iron pipes are inserted, with the bell end turned upward. These were kept bailed out while the work was in progress, the asphalt being brought up around each, and a tight connection made by means of the cement. When the work was completed, cast-iron tops were fitted to these pipes, in the centre of which was a flap valve about two inches in diameter of leather, weighed down by a disc of iron sufficient to sustain a pressure of a few ounces from the water confined in the well. By this means it is evident that the asphalt lining will not have to sustain any material stress because of the subsoil water when the reservoir is empty, and no leakage can take place when the pressure of the water in the reservoir exceeds that of the water underneath.

A method of lining reservoirs with an asphaltic concrete has been described* which, although resembling the above in principle, might be mentioned. The mixture consisted of twenty-five parts clean sand, seventy-five of gravel, and ten of asphaltic cement, the operations being carried on as usual, except that the concrete was tamped and then rolled with hot rollers. The thickness of this lining was on the bottom three and one-half inches, running down to two and one-half inches near the top of the slopes, the total cost being $1.15 per square yard.

An account of the magnificent system of waterworks which have been just completed for the city of Portland, Oregon, has recently come under my notice, and, as asphaltum played a very important part in the construction of the reservoirs, it might be interesting to give an outline of this work, and the manner in which the asphalt was used, as it is somewhat unique.

The water is led from the Bull Run River through a steel conduit (varying in diameter from 35″ to 42″) for twenty-four miles to the high service distributing reservoir at Mount Tabor, 400 feet above and six miles from the city. The system also includes three other reservoirs, two of which are located in the city parks, the combined capacity of all these reservoirs being 68,000,000 gallons. The head works at the Bull Run River are at an elevation of 710 feet above the level of the Willamette River at Portland. The surplus energy of the water due to this fall is utilized for the generation of electricity for lighting purposes.

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*"Asphaltum in Irrigation Works," by Mr. Purcell, in Trans. Inst. C.E., Vol. 90.

Three of these reservoirs referred to are lined with concrete, strengthened with twisted iron bars, and finished with pure asphaltic cement, while the remaining one is lined with a double course of brick laid in asphaltum. The construction of the latter is especially interesting. Each brick before being laid is dipped in asphaltic cement made, as above described, with pure Californian asphalt and maltha. When the first course was finished the surface was given a good coat of cement, on which the next course of brick was laid in the opposite direction, the surface being finished off with a final coat of asphaltic cement.

This reservoir has a capacity of 22,000,000 gallons, the slopes being one and a half to one. As an instance of the strength and quality of this lining the following case is instructive. A large boulder had been left in one of the slopes. As the surrounding earth had not been sufficiently compressed settlement occurred to the extent of eight inches about the stone, without, however, causing the least fracture, the lining being still perfectly tight.

All gate houses and water chambers in connection with this system are lined with asphaltum.

The extensive and elaborate nature of these works may be inferred when we consider that the estimated cost of the system complete amounted to $3,518,896. Mr. James D. Schuyler, previously referred to, who is one of the most eminent of American hydraulic engineers, had charge of the work.

ASPHALTIC MASONRY.—Mr. W. C. Ambrose, M.Am. Soc. C.E.,* describes a very successful use of asphaltum in the construction of sea walls. The situation was on the Pacific coast, where a railway was built along the top of the bluffs facing the ocean for several miles. Owing to the unstable nature of the strata, the sea was gradually encroaching on the land, so that some method of protection against its force became imperative. Piling was impracticable on account of the bed rock, and the building of a concrete wall was beset with many difficulties, besides being expensive there. It was decided to build a wall of stone, cemented with asphaltum obtained from a mine in the locality.

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* Trans. Am. Soc. C.E., Vol. 24.

The wall was made six feet wide at the base, two feet wide at the top, and nine feet high, the back being built vertical and close up against the cliff. The mode of construction was simple. A layer of stone was laid, then melted asphalt was poured on, then another layer of stone was placed in position and more asphalt added to fill up all interstices and adhere to the layer below. The fact that no vibration is caused by shock in a wall like this may account for its success.

For many years, the use of asphaltic concrete as a foundation for heavy machinery has become prevalent in Europe, as it has been found to solve the question of vibration simply and absolutely. This it does, owing to its plasticity and entire want of vibration under heavy shock, and, therefore, in such cases, is very superior to ordinary concrete. The proportions adopted in a case of its application in New York as a foundation for heavy steam and drop hammers were :

Asphaltic cement	8½	per cent.
Lime dust	6½	"
Sand	36	"
Crushed limestone	49	"
	100	

Total quantity made at once, *i.e.*, one batch, weighs 820 pounds.

The foundation is encased in a wooden box, firmly braced with rods, and the material was deposited in layers four inches deep, each being firmly tamped before being covered by the next. With such a foundation, no shock can be felt in the adjacent buildings, with all the heavy machinery running right beside them.

In California, where the natural asphaltum is so abundant, it is further used in the foundations and walls of buildings. It has thus been used in building some of the finest mansions in the state. The object for which it is applied is to prevent damp from rising in the walls from the subsoil; a few of the lower course being laid in asphalt will effectually prevent this. It is coming more and more into use in the Western States, replacing Portland cement in many cases.

MINOR USES.—As a preserver of piling in the sea against the teredo and other such enemies, a coat of asphaltum is very efficient ; also it makes one of the best coatings for iron pipe, and is much used in this capacity in the numerous hydraulic works of California.

As a roofing material it is superior to coal tar, being more stable, and not losing its lighter oils, and becoming brittle on exposure to the weather.

A few of the well-known uses to which asphaltum is put in the arts will be merely mentioned, the most important of these being: in electric insulation, in the manufacture of fine varnishes, in photography, photolithography, and photo-engraving, in the lining of wooden flumes and vats, and in the protection of these from the action of chemicals.

Examples might be multiplied in which this invaluable material, whose possibilties are perhaps all too little known and understood by engineers generally, has been made to fill a few of the wants of this age of advance. The foregoing is intended as a simple digest of the principal uses to which this material has been put, with the object of placing these in such a form as to give the members of this Society a comprehensive view of the part which asphalt may take in engineering construction.

Toronto, Ont., Feb. 23, 1895.

DISCUSSION

Dr. Ellis.—When Mr. Speller began to work at asphalt, he found very little help from the published works of other chemists. Mr. Speller has done much careful painstaking work in this difficult field. The question what relation there is between the chemical composition and the physical properties of asphalt is one of great interest, but one of which next to nothing is known; indeed, our knowledge of the chemical composition of asphalt is of the vaguest.

Mr. Speller's work will help to solve these very interesting problems in applied chemistry.

Mr. C. H. Mitchell.—I consider Mr. Speller's paper on asphaltum of great value, particularly at this stage of its success as a matertial of engineering. True, the paper suggests mere possibilities, and does not pretend to do more than present a synopsis of the valuable uses to which the material can be put. We have been so apt to consider the use of asphalt to be relegated to only one department—that of paving—that the suggestions in Mr. Speller's outline have appeared quite novel. This has been caused for the most part, perhaps, through ignorance of the nature of the substance.

The result obtained in the tests which the author has presented are certainly interesting. I had always been of the opinion, with my own slight acquaintance with asphalt, that in our climate the use of the substance as a cement would be very hazardous, on account of the apparent difficulty of making secure and homogeneous joints to withstand extremes of temperature. From the tests which Mr. Speller quotes, however, it appears that with a large factor of safety the tensile strength should be sufficiently grea to permit of its limited use in masonry construction. In our climate, we are subject to temperatures of from, say, 20° below zero to 100° above, where masonry would be concerned. It would, no doubt, be difficult to make actual tests on asphaltic cement under these conditions, but it seems to me that before we can place very much faith in the general use of asphalt as a cement we must have tests under these temperatures. Then, too, it appears from rough observation that the rates of contraction of asphaltum by cold air are greater than those of stone or brick, which fact is not to be overlooked. Of course, the substance is very elastic, but it seems that this decreases at low temperature. I have found no figures giving these rates, and if the writer can give us such it would be acceptable as general information.

The use of asphalt in reservoir lining seems to have grown much in favor in the West, where, of course, it is cheaper. There is, indeed, much in its favor, especially the fact that it needs little foundation. As far as I can learn, literature on the details of the construction is not plentiful. Mr. Speller has given us a brief outline of such ; if he could indicate references on the subject, it would be of value to us in familiarizing ourselves with it. Has there been as yet any objection found to this lining from a sanitary point of view ? Would the organic matter have any action on the water, and would the taste be affected ?

The roadway department of Toronto seems to have gone into the subject of asphalt to a great extent. Could Mr. Speller inform us as to the comparative results with other similar series of tests, in other places, in reference to tensile and crushing strength ?

MR. F. N. SPELLER.—In reply to Mr. Mitchell, I must say it would be certainly valuable to obtain tests at the extremely low temperature mentioned by Mr. Mitchell, in most cases, though I think that the masonry construction would be subjected to less extremes of temperature than those mentioned above. In the case of foundations, they would be protected from such extremes largely by the surrounding earth, and the poor conducting material with which they were built. The asphaltic cement must, of course, be manufactured for the particular conditions of temperature which it is required to stand, no one formula or penetration being applicable for every place and situation.

The elasticity doubtless decreases with the temperature, but it will be observed that the tensile strength increases at the same time, although the limit to this increase has not yet been found. A curious factor in the success of the sea wall described in the above paper seems to have been that although, when the tide was out, the wall was exposed to the severe rays of a California sun, which, of course, diminished the strength of the asphalt, yet when the water returned and strength was required the very would-be destroying agent supplied this resistance by cooling the wall. As to the contraction, the difficulties in obtaining the rate of the same are obvious, owing to the tendency of the material to flow. I have watched Clifford Richardson, U.S. Government chemist and expert in asphalt, in his laboratory at Washington, conducting experiments to this end with cylinders of asphalt eight inches long, and after taking every known precaution, and making numerous experiments, the results were small, but discordant, some actually showing an expansion on cooling, which, of course, means that the figures obtained were unreliable, and also that the rate of expansion is probably low. It is highly desirable that the co-efficient of expansion should be determined, and I intend trying an indirect method for the solution of this problem by careful determinations of the specific gravity (by the bottle) at different temperatures.

The literature on the subject of reservoir lining is exceedingly meagre in quantity. A paper by Mr. Schuyler, in Transactions of the American Society of Civil Engineers, Vol. xxvii., 1892, is the only thing I know of in that line. A large part of the information which I have endeavored to embody in the above imperfect attempt has been obtained by personal correspondence. As the Portland system of waterworks, to which I have briefly referred, is only just finished, we have heard little about it in the engineeringp apers so far, and I desire to express my thanks to Mr. J. S. Jackson, contractor for the asphalt work there, for a detailed account of the work, with which he was kind enough to furnish me.

One of the advantages of the asphalt lining, as I understand, is that it is perfectly sanitary, and imparts no taste to the water.

With regard to the last question of Mr. Mitchell, I would say that when the tests referred to were started no knowledge of any similar line of work was to hand, and from diligent inquiries since I find that very little seems to have been done in that line, which is surprising, as it seems to be a natural and practical mode of test. In order to draw out some information on the matter, the writer published a short account of his work in the *Paving and Municipal Engineering Journal* (November, 1894), and received, as a result, considerable correspondence on the matter of an inquiring nature. The only account of previous experiments was from a gentleman who recently had made such, using a breaking cross section of one-eighth square inch, applying the stress as quickly as possible, and who was surprised to obtain results twice as great as those given above.

It is needless to point out that standard uniform methods must be adhered to in this matter, or the results will be practically useless, except, perhaps, to the person making them.

HARDENING AND TEMPERING STEEL

E. F. Shipe, '96.

In presenting this paper to the Society, it is necessary to state that this is not a discussion of the subject in its broadest sense, but rather a view from the standpoint of a workman engaged in practical shop work.

In dealing with iron, in its various forms, there are no other two properties of such value as those steel alone possesses, namely, hardening and tempering, which enable us to work different materials into any desired shape, and a knowledge of the best methods of getting good tools from steel is a very important part of an engineer's education.

The terms, hardening and tempering, are used to describe the two principal operations in preparing steel for tools, closely connected with which are forging and annealing, the character and quality of the work often depending quite as much on the care given the steel before being hardened and tempered as upon the last-mentioned operations.

In forging steel that is afterwards to be tempered, it is not sufficient to hammer away until the required shape is secured, for in hardening there will be considerable straining in the steel, which must not be made greater by poor forging.

The grain in steel, or, at least, the line along which it flows easiest, is always lengthwise of the bar, and should be kept, as nearly as possible, straight, or in even curves, and not violently driven to one side at a sharp angle.

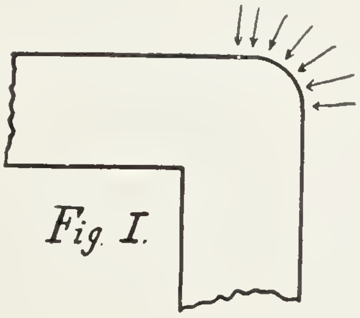

Fig. I.

In giving a new shape to a piece of steel, it should be driven gradually into the desired shape, and the flow of the metal aided by proper hammering: for example, in bending a sharp corner, as in Fig. I., the hot steel is laid on the anvil, and the outer half forced down into its position by striking on the end only, the fibres of the steel being stretched at the outside, or compressed at the inside, the inside fibres, however, being cooled by contact with the anvil, the outside ones are compelled to stretch beyond their limit, and small cracks will be formed or started, which will rapidly develop when the piece is hardened. To prevent this straining of the steel, the hammer should be used on top and around the corner, by this means driving the fibres together and stretching them by the blows in the direction they are to assume. These blows should be evenly distributed over the surface, and during the time the heavier blows are bending the piece around.

If the piece be flat, and it is desired to have it square in the corner, work on the sides should alternate with that on the bend, and, when the piece is finished, the metal will appear somewhat rounded at the corner, as in Fig. II., the lines passing around in curves instead of making angles.

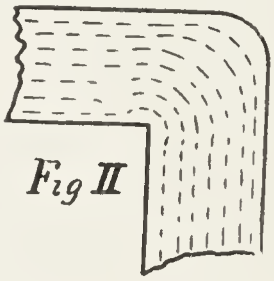

Fig II

Butt-ending or stoving—that is, striking a bar on the end to enlarge it—is a common but very poor way of treating steel that is afterwards to be tempered. There is little chance to keep the fibres compacted, and the chief part of the work falls on the centre, which becomes more dense than the remainder. Such treatment, if carried to any extent, almost invariably produces cracks or checks all around the end, as in Fig. III., and makes a piece it is impossible to harden without cracking.

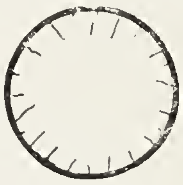

Fig III.

All pieces that are forged should receive practically the same treatment all over, in order that the density, which is increased by hammering, may be as uniform as possible. As a piece gets cooler on the anvil, the blows should get lighter, for when the steel is hot it is easily forced to flow from under the hammer, but, as it gets cooler, it resists this action, and the blows tend to compress the fibres, and will cause surface strains unless they are lighter. In forging small tools, as chisels, lathe tools, and the like, so much care is not needed, but it is best to hammer uniformly, keeping the stock as nearly square as practical, so that the effect of the blows will be even throughout the piece.

During the process of forging, great care should be used so as not to heat the steel too hot. Above a bright red heat, steel readily takes up inpurities from the fire, and, on hardening, it becomes quite granular, and entirely worthless for cutting tools, though it may look all right. In cases where steel has been "burned," as such overheating is called in the shop, the only safe plan is to cut off all that is injured.

No matter how carefully steel may have been forged, there will be certain strains in parts, and some places will be harder than others from contact with the cold anvil. To modify these conditions and make the piece more easily worked, it is generally annealed or softened, which is done by heating to a good red heat, covering with lime, ashes, or charcoal, and allowing it to cool slowly. If heated hot enough, any strains that may have been caused by the hammering will have a chance to adjust themselves.

If the piece be small and of a regular shape, a very good and quick plan is to "water anneal." This is done by quenching the steel in water after it has cooled from bright red until it just shows red in the dark. This method leaves the steel in a very "open" condition, so that it works nicely with a file.

After forging and annealing, nearly all tools, except the simpler ones, such as chisels and lathe tools, are machined to the proper shape before being tempered. Where it is possible, it is best to temper just as the work leaves the hammer, for the outer surface is close-grained from the working it has received, and the tool will do better service than if this thin layer be ground away.

Owing to the many grades of steel, it is difficult to describe exactly the processes used to harden them; but in general, for common tool steel, all that is required is that it be heated a good red and then suddenly cooled. Of course, there are many ways of accomplishing this, varying from heavy armor plate heated in reverberatory furnaces and chilled in immense shower baths down to the small drills used by watchmakers, which are heated in the flame of an alcohol lamp and chilled by waving in the air.

We may divide the work of hardening and tempering in the ordinary shop into three classes:

First, such tools as are hardened for only a part of their length, and the temper drawn by using the heat that remains in the rest of the tool. In this class are cold chisels, flat drills, lathe tools, etc.

Second, tools that are hardened all over, and tempered by applying heat from some outside source. In this class are milling cutters, reamers, twist drills, and dies for many kinds of work, as well as springs of various sorts.

The third class includes tools, dies, and parts of machines that are required to be as hard as water will make them, and in which the temper is not drawn at all, or else at the same time as the hardening.

The first class contains the greater part of the work in tempering done in the ordinary shop, and every mechanic should know the various ways of doing it properly.

Having first seen that the piece or tool is in the desired shape, the next thing is to heat it to a good red heat. This will vary in different classes of steel, but should never be more than just enough to harden in the particular quenching fluid it is intended to use. It is best to use a charcoal fire, but, where this cannot be had, a coal fire, well burned down and clean, may be used. The addition of a handful of common salt will keep the work free from scale, and aid in obtaining uniform results. The article should be drawn from the fire as soon as it is uniformly heated over the part it is desired to temper, as longer exposure to the fire gives more opportunity for injurious elements to combine with the steel. In heating a tool having a light point and a heavy body, as ordinary cold chisels or lathe tools, it is best to place the point well through the fire and heat the body of the tool first, then draw in until the point is at the required temperature. After heating properly, if the piece is to be hardened, it is drawn from the fire and plunged into some fluid which will cool it suddenly.

In the choice of quenching fluids there is much difference of opinion amongst those engaged in this kind of work ; but clear, cold salt water will harden about as hard as any fluid except mercury, which, of course, is not to be had in the average shop.

Different workmen advocate the addition of various substances to the water as an aid in hardening, but the general utility of these is open to question, since equally good results are obtained with clear water. For some work oil is used, its effect not being so marked as that of water, and work is less liable to crack, which is also often prevented by cooling in hot water.

In dipping a tool, suitable tongs should be provided, so that it may be held securely in any desired position, and that part of the tool which is to be the cutting edge should strike the water first. I here refer only to the common class of bench or lathe tools having a comparatively short cutting edge. Only as much should be hardened as will be used before the tool must be redressed, and, to prevent the line of hardening being sharply marked, the tool should be drawn in and out of the water for a short distance while it is cooling.

Practice alone can determine just how long to cool the hardened part, but it will be found best to cool so that the heat left in the body of the tool will be but little above that necessary to draw the required color, for the piece will be tougher if this be drawn slowly instead of rapidly, and the colors will occupy a wider space and give one a better chance to secure the exact temper required.

After dipping a tool to harden it, it is roughly brightened on the hardened part by rubbing with a piece of stone or emery cloth, which makes a bright clean surface, where the colors are easily distinguished from each other. These colors, as they appear on steel as it is heated, serve to indicate the temperature rather than the hardness, for they will show on a piece of polished iron as well as on hardened steel. We, therefore, must make sure that the tool was hardened before we attempt to draw the temper, or the tool will be worthless, so far as cutting qualities are concerned, although of the proper color. If quite hard and clean, steel has a mottled-gray appearance as it is taken from the hardening bath, but, if at all in doubt, it is best to try if an old file will cut it. If it will not, the piece is hard, and the drawing of the temper may be completed.

The colors, as they appear on hardened steel, change from light straw to dark straw, brown, purple, blue, blue tinged with green down to gray, when all the hardness has been practically removed. These colors are said to be caused by oxidation, and this being increased by heat, up to a certain point, we get the various colors. The fact is, however, of more importance to us than the theory.

In deciding upon any certain color for a tool, the work it is to do and the grade of steel used must be known by the operator to get the best results. It is best to use but one grade of steel for each class of tools—and this should be a good grade—in order that the men may become familiar with it, and find, by experiment, the particular temper best adapted for the work it is to do. In general, a tool should be left as hard as possible, and still stand the work without crumbling. For most steel, a good straw color is used for ordinary work in cast or wrought iron, while for working steel tools are left a light straw color.

In the case of thin tools, only the cutting edge should be hard, and the back or underside should be drawn well into purple or blue, in order that it may be tougher and more elastic. Cold chisels vary in color from dark-brown to blue, according to the work they are to do, and should be nearly uniform in color within about one-half inch of the end to allow for grinding.

Only by experience can one learn to have just the proper amount of heat in the body of the tool to do the drawing, although the heat may be easily increased by placing the tool over the fire or on a hot piece of metal. Very light work, in which the color is apt to run too rapidly, is best tempered by using a gas jet after hardening and polishing, by means of which one may have ample time to check the cooling at the proper moment.

In tempering tools of the second class—such as milling cutters, reamers, various sorts of dies, and the like—considerable difficulty is experienced in obtaining uniform results on account of the great variety of shapes.

Tools that are practically uniform in cross section as reamers or taps need to be evenly heated, which is best done by keeping them turning in the fire. They are dipped endwise to harden. After polishing, the temper may be drawn in melted lead, hot sand, or, very conveniently, in a piece of gas pipe kept hot in the forge fire, the progress of the work being easily noted in the last method, and it is convenient. The shanks of such tools are always drawn to a dark-blue, in order that they may not snap off under sudden strains. Long pieces of this class will spring, even under the most careful treatment, but may be straightened while at their tempering heat by placing between centres and applying pressure to the higher parts.

Milling cutters and pieces of similar shape are very liable to crack in hardening. If possible, avoid key seats in such tools, or, if they must be provided, have them round on the bottom, as this is not nearly so liable to crack as if square in the corners.

Tools of this class are often hardened in oil, the heat being just enough to insure their hardening. After polishing, they may be drawn in various ways, but a red-hot bar passed through the hole will give good results, and leave the centre soft and the tool less liable to crack than if of uniform hardness throughout.

Dies for cutting out various shapes often assume very complicated forms, and in the tempering of these will be found some very difficult work along this line. Owing to the peculiar shapes, great care is necessary in heating and dipping, so that unequal expansion or contraction may not distort the finished die. On account of the varying nature of this class of work, only a general summary of the points requiring care can be given here.

The selection of the steel is of first importance, and special brands made for such work should be used. The forging and first annealing should be carefully done, and, after rough dressing to nearly the desired shape, it is a good plan to anneal the second time. This will allow of any readjustment that the removal of the outer surface may have allowed, and aids the operator in getting out work that is true and not badly warped. After dressing to final shape, all sharp corners or holes should be filled with dry fire-clay, which prevents access of water to one part more than another, and, by causing uniform cooling, prevents cracking. If there should be a heavy part to the die, this is usually dipped first, in order that it may partly contract before the lighter parts are cooled.

The springing of this class of work often causes considerable trouble, and is often due to uneven heating rather than to the hardening. If a piece, as Fig. IV., be placed on the fire and heated rapidly on the underside, while the top remains exposed to the air and practically cool, it will assume a shape like Fig. V., on account of the expansion of the lower layers. This expansion is about one-eighth of an inch per foot in passing from a black to a red heat, and this must be accommodated in some manner. If thin, the piece bends to allow for part of this expansion, but, if heavy, the hot metal is not strong enough to bend the colder parts, but is forced to compress to relieve the expansion. If now the piece be cooled, this compressed part will contract the usual amount; and, when cold, the piece will be curved just the opposite way to that shown in Fig. V. This will show how needful is slow, even heating, and in this class of work great care is needed at every step.

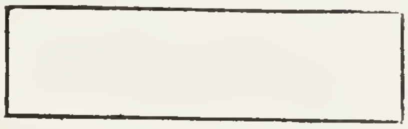
Fig IV.

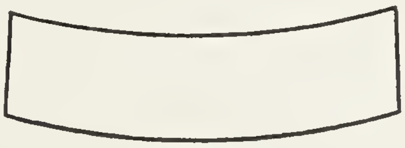
Fig. V.

Such tools or dies have usually only one cutting edge, and the writer has found the use of potassium cyanide (KCN) very beneficial. The addition of a very little causes steel to become hard when chilled at a comparatively low heat, and if the edges of a die be "flowed" over with KCN while at a low red heat it will spread over part in a glass-like film, and the die may be dipped at such a heat that it will harden only where the cyanide has been placed. The remainder of the die will remain soft, and this almost entirely evercomes the danger from cracking. The work is not nearly so liable to be distorted, since the heat and consequent expansion and shrinkage are not so great as when hardened without this treatment.

After having succeeded in hardening this class of work, it is polished, and then generally placed on a heavy piece of red-hot plate with the cutting edge up. The progress of the drawing of the temper is easily observed along the sides or on the top, and when the proper color is reached they are usually quenched in oil.

After hardening steel rings, they are usually found to be somewhat larger on the outside than they were before heating, while the holes are smaller. This is probably due to the outside layers being chilled while held in their expanded shape by the metal in the inside.

Springs of many kinds have their temper drawn by a process called "blazing," a heavy oil being poured over them after hardening, and they are then held over the fire until this burns off. Experience, however, is the only guide in this kind of work, which varies very much.

In the third division we have made are included dies for stamping coins, medals, and similar work, special spindles, and wearing parts of machines, as well as special tools for cutting chilled iron or steel.

The work done by dies in striking coin is very hard, and they are usually made of such a grade of steel as will allow of the dies being hardened without drawing the temper. In heating such work, the engraved surface must not be allowed to scale in the least, the medal dies being heated in charcoal or lead.

In hardening, they are first dipped for a moment in strong acid to thoroughly clean the face, and then placed in a stream of cold water, which strikes the face, such as that from a common water tap. Spindles and wearing surfaces are usually left large enough to be ground to size after hardening. Many different processes are used in doing this class of work, and scarcely two men will be found who use the same means for arriving at the same end. In making tools especially hard for cutting chilled iron, each workman or shop has some particular formula, but the greater part depends on the quality of the steel used rather than on the quenching fluid.

In a few cases it is possible to harden and draw the temper at practically one operation, or, in other words, harden to a less degree than the usual cooling in water produces. As examples of this, I might refer to tinsmiths who temper cold chisels by driving the hot chisel into a bar of lead, the only examples in the common shop being in the tempering of very small drills, chisels, and scribers by heating red-hot and forcing into a bar of soap. This gives a very durable point for this class of work, and is both quick and sure, but must be termed an accident rather than a process in tempering.

There may be many other short ways of tempering that are reliable, and, no doubt, many more are possible ; which, therefore, offers plenty of room for the satisfaction of the desire for "original research." The entire subject is one of great practical importance, and will prove of much interest, should any of you decide to try to answer many of the questions that still remain unsettled.

Toronto, Jan. 8, 1895.

GEAR CUTTING

H. V. Haight, '96.

Before proceeding to consider gear cutting, it might be well to look at the different methods of making gear wheels.

Gears may be made in several ways :

(1) They may be cast with the teeth in them.

(2) They may be cast with mortises in them, into which the teeth are afterwards driven.

(3) The teeth may be cast on the gear, but finished by a machine.

(4) The teeth may be cut out of the solid.

Each of these methods has its advantages. When made in quantity, the gears with cast teeth are generally cheaper than those with teeth cut from the solid. I quote from the catalogue of Geo. B. Grant, a manufacturer of both cut and cast gears: "Cast teeth are cheaper only for gears in considerable quantity, unless they are list gears, as special patterns must be made for special gears." Cast teeth are usually stronger than cut ones, as the skin of the metal is the strongest part. Cast iron is the material generally used for cast gears, but those weighing less than half a pound can generally be made cheaper of brass. Where great strength is required, as in a punch or shear, the gears may be cast of mild steel.

In gears with inserted teeth, the teeth are often made of wood, and a gear with wooden teeth, meshing with one with iron teeth, will run with very little noise or friction. Such a pair is often used in mills or factories to connect lines of shafting. In a pair of gears like this the wooden teeth are often made a little thicker than the iron ones, in order that they may be of equal strength.

The third method referred to of making gears is that of casting them with the teeth in, and then finishing these with a machine. This method is only used, so far as I am aware, for heavy gearing, and would appear to be a good method for such, for in order to cut the teeth out of the solid it would be necessary to remove a large amount of metal.

Cut gears, by which is meant those with teeth cut out of the solid, are coming more and more into use all the time. Methods of making these have been so improved as to make them almost as cheap as cast ones. Cut gears have many advantages over cast, for the teeth are more nearly of the theoretical form, and the surfaces are much smoother; as a consequence, the teeth fit better and work with less friction. Another advantage is that they can be made of material which cannot be cast, such as forged steel, sheet brass, fibre or rawhide. The chief advantage of cut gears, however, is their greater accuracy, and in the trains of gearing in screw-cutting lathes, milling machines, clocks, etc., they have come to be a necessity.

In a screw-cutting lathe, for instance, if one gear is to run one-third as fast as the next one, it is not only necessary for it to have three times as many teeth, but at every instant the velocity of one must be three times that of the other. This constant velocity ratio can best be obtained by the use of cut gears.

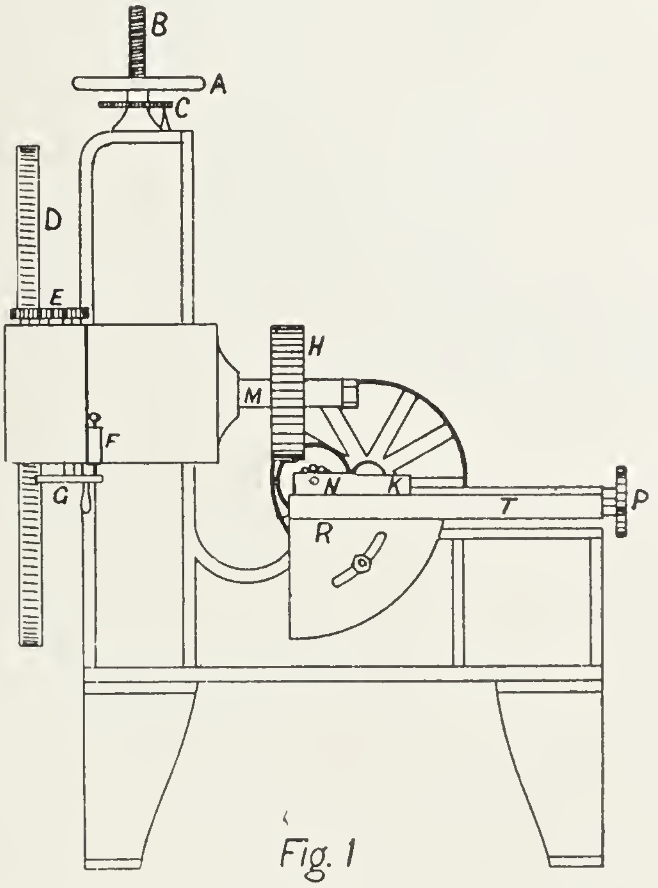

Fig. 1

Fig. 1 represents a gear-cutting machine of a somewhat common type. M is the mandrel upon which is placed the gear to be cut. Upon the same axis as M, and turning with it, is the worm wheel D of the dividing head, this head being for the purpose of dividing the circumference of the gear into parts, equal to the number of teeth required. It consists of the worm gear D, a worm in mesh with it and the change gears E, one of which is connected to the worm, and another to the plate G; the plate G can be turned by the handle, and can be locked after each revolution by the pin F. By placing the proper change gears at E, we may get any number of teeth we wish in the gear H.

The teeth are cut by a rotary cutter N. The saddle R, upon which the cutter spindle is mounted, works in the horizontal slide T, below the gear, and is moved along this slide automatically by a screw and the gears P.

The head which carries the work mandrel and the indexing mechanism is adjusted vertically by the hand wheel A, which turns like a nut on a screw, B, fastened to it. This screw has four threads per inch, and the circumference of the plate C attached to A is divided into 250 parts, so that one division on the plate corresponds to one-thousandth of an inch. This enables the gear to be adjusted vertically, so that the cut will be the exact depth required, which is very important, especially with cycloidal teeth.

In the machine described, the cutter is fed through the gear and stopped automatically, but it is necessary to pull back the slide and turn the indexing mechanism by hand. This type of machine is called half-automatic. The most improved machines are entirely automatic, requiring no attention from the time the gear is put on the mandrel until it is ready to be taken off, which is quite an advantage, as a large gear may easily take half a day to cut, and an entirely automatic machine would require no attention during that time.

Fig. 2 is a cut of an entirely automatic gear cutter, designed for cutting heavy spur gears only. I am indebted to Messrs. Gould & Eberhardt for their kindness in sending me the cut.

The cutters used to cut the teeth have clearance behind the cutting edge, but the shape of a cross section along any radius is the same, which enables the teeth of the cutter to be sharpened on the face without changing their form. The cutters are made in a special machine, which is said to give a theoretically correct form, that is to say, the curve is not a copy of the curve on some cam in the machine, which may itself be far from correct, but is generated by the motions of the machine.

The system of cutters most in use is Brown & Sharpe's, and, as many other manufacturers of gears and cutters follow this system, it may be well to give a short description of it. First, let us note some of the general terms used in describing gears. The curved outline of a tooth is often called its *profile*. That part of the profile which is above the pitch line is called the *face*, that part below the pitch line the *flank*. The whole of he tooth above the pitch surface is called the *point*, that below it the *root*,

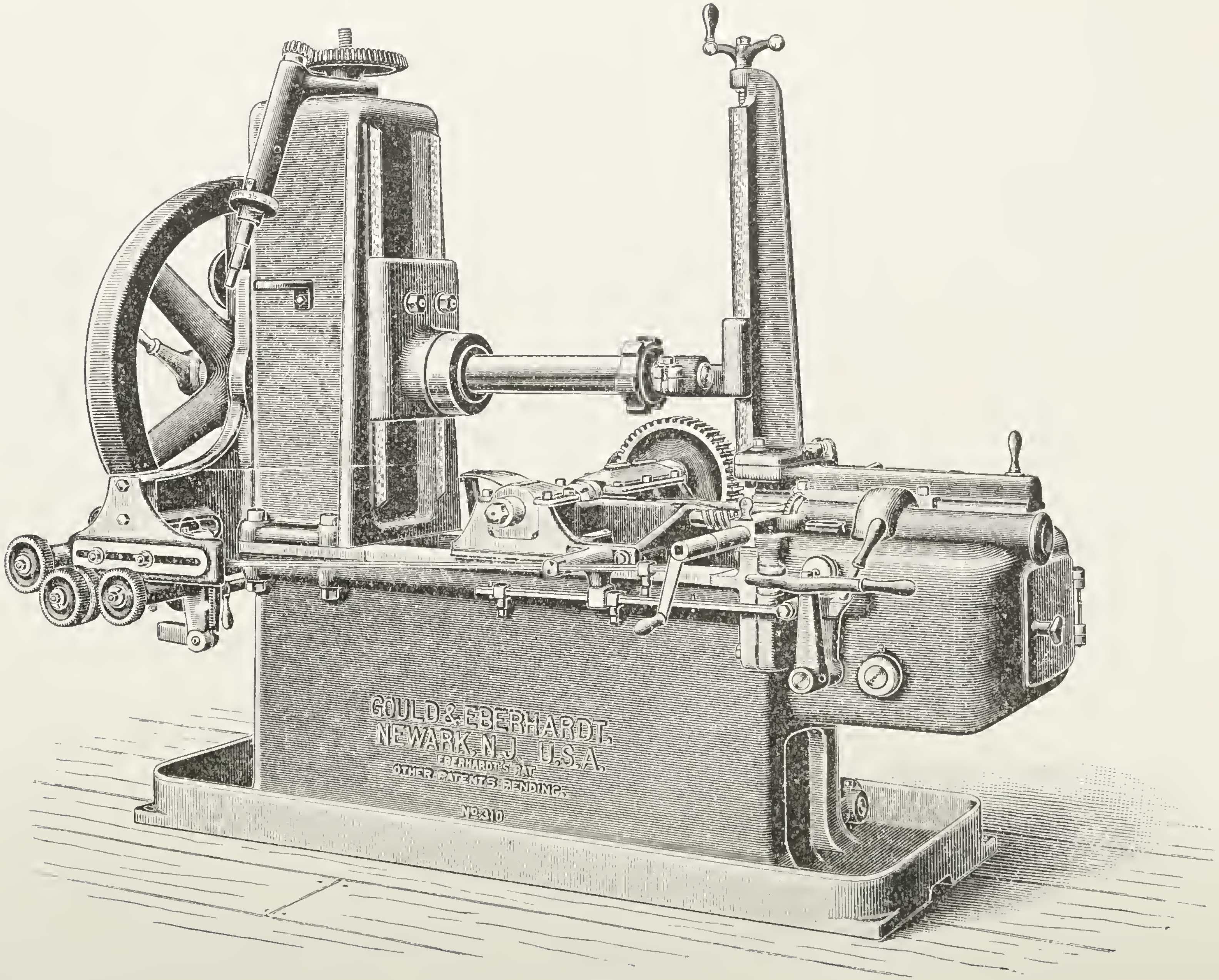
GOULD & EBERHARDT.
NEWARK, N.J. U.S.A.
EBERHARDT'S PAT.
OTHER PATENTS PENDING.
No. 310

Fig. 2

while the height of the tooth above the pitch line is called the *addendum.*

The size of gear teeth may be given in either *circular* or *diametral pitch.* *Circular pitch* (see Fig. 3) is the width of a tooth and a space at the pitch line, *measured along the pitch line* (if we measure in a straight line, we get what is called *chord pitch*). *Diametral pitch* is the number of teeth to each inch of the pitch diameter, and is evidently equal to 3.1416 divided by the circular pitch ($P = \frac{3.1416}{P^1}$). Note that the circular pitch is given in *inches*, while the diametral pitch is an abstract number.

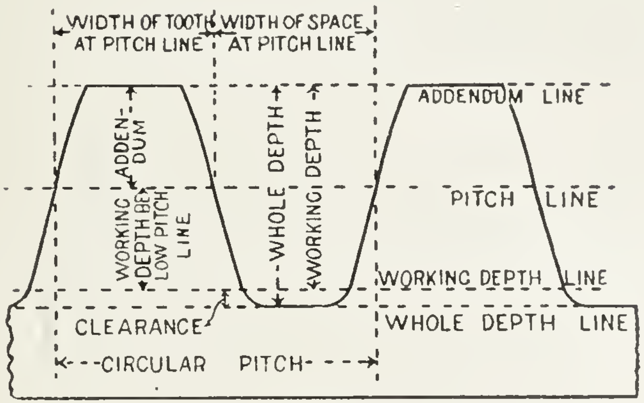

Fig. 3

In Brown & Sharpe's system of gearing, for cut gears, the addendum, or height above the pitch line, and the working depth below the pitch line (see Fig. 3), are each made equal to one inch divided by the diametral pitch, and the clearance at the bottom of the space $\frac{1}{20}$ of the circular pitch. Some manufacturers make the clearance $\frac{1}{16}$ of the working depth of the tooth, or about $\frac{1}{25}$ of the circular pitch. The width of the tooth at the pitch line is made equal to the width of the space at the pitch line.

In the Brown & Sharpe system the fewest number of teeth cut in a gear (either involute or cycloidal form) is twelve, the other extreme, of course, being a rack. For involute gears the angle of pressure is 14½ degrees, and eight cutters of each pitch are required to cut a complete set of gears, from a twelve-tooth pinion to a rack. For cycloidal gears, the diameter of the describing circle is equal to the radius of the fifteen-tooth gear, twenty-four cutters being required for each pitch.

Gears with involute teeth are used to a greater extent than those with cycloidal teeth (the manufacturers call them epicycloidal) for two reasons —first, involute gears require fewer cutters ; second, they will run at different distances between centres and maintain a constant velocity ratio. In the change gears of a lathe, for instance, a pair of involute gears will run quite well when half out of mesh, while with a pair of epicycloidal gears in the same place there would be likely to be considerable noise, and the velocity ratio would vary. A disadvantage of involute gears is their tendency to crowd between centres, and for this reason the epicycloidal teeth are preferred for heavy gearing.

The following extract from a letter from a firm which manufactures gears may be of interest, as it shows methods in actual use by manufacturers:

"We have in our works both Brown & Sharpe and Gould & Eberhardt machines. All our gears are cut with Brown & Sharpe patent involute cutters. We believe this form to be far preferable for general requirements, and, indeed, in our judgment, it is very doubtful if the epicycloidal form possesses any points of real advantage.

"We measure the teeth on all gears with compound vernier calipers, especially constructed for gear teeth. These calipers enable us to measure the distance from the top of the tooth to the pitch line within one-thousandth of an inch, and at the same time to measure the exact thickness at the pitch line. All our gears are tested on special gear-testing machines. The Spur gear-tester carries two studs which are exactly perpendicular to the bed of the machine, and is provided with a vernier, which enables us to test the gears at exactly the correct centre distance. The Bevel gear-tester is provided with two spindles exactly perpendicular to each other, and the central lines of these two spindles are in the same plane.

"Very truly yours,

"LELAND, FAULCONER & NORTON CO."

Large gears and racks are often cut by some form of planing process.

Fig. 4 represents a shaper arranged for cutting racks. This shaper is a large one (16 in. stroke, 66 in. travel) of the style in which the work remains stationary, and the feeding is done by moving the saddle in which the ram works. The principal change necessary to arrange this machine for cutting racks was some method by which the saddle could be moved to a distance just equal to the pitch of the rack, after cutting each tooth. This was accomplished by putting an index plate A on an arbor of one of the feed gears. The plate is stationary, and in front of it is an index arm, which revolves with the gear, every revolution of which moves the saddle one-quarter of an inch. Near the edge of the plate is a row of 250 holes, thus one division on the plate corresponds to .001 of an inch. The two arms D and E of the spacer may be clamped together in any position, and thus save the trouble of counting the holes every time.

Let us note briefly the process of cutting a rack on this shaper. Suppose it is three pitch, the circular pitch corresponding to this being 1.047 inches. This will take four complete turns of the index arm and 47 spaces, so we set the two arms of the spacer with 48 holes between them, and the micrometer screw M at the back of the slide for a depth of .719 inches, which is the whole depth of a three-pitch tooth. We put into the tool post a rib tool, as wide as the bottom of the space, and cut a straight groove the depth of the tooth. The index arm is then turned by means of the handle B through four revolutions and 47 spaces and another groove cut, and so on, until the whole rack is cut in this way; then we remove the rib tool and put in a special tool (Fig. 5) the exact shape of the space, and cut through as before. This second tool is made by forging and then filing a piece of steel to fit a template like Fig 6. For involute teeth the flanks of the teeth are straight, and at an angle of 29° to one another, and the faces are rounded off slightly to prevent interference when working with a small pinion. This template is also used to set the tool perpendicular to the rack.

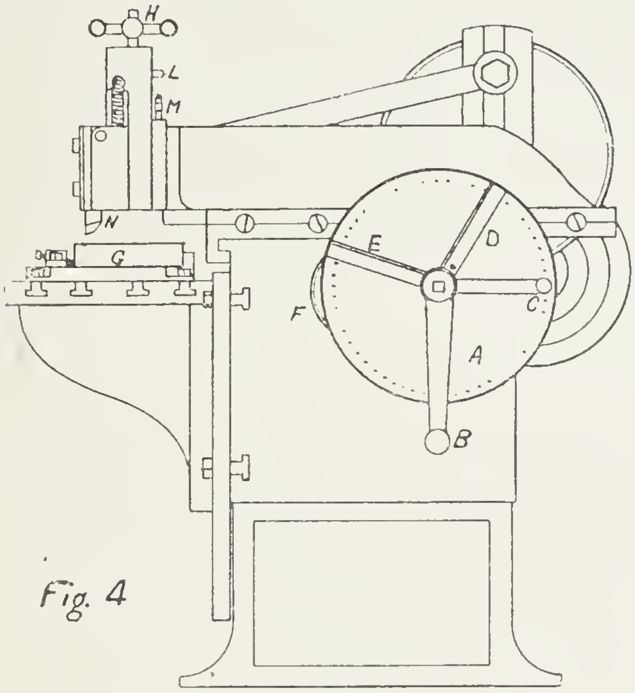

Fig. 4

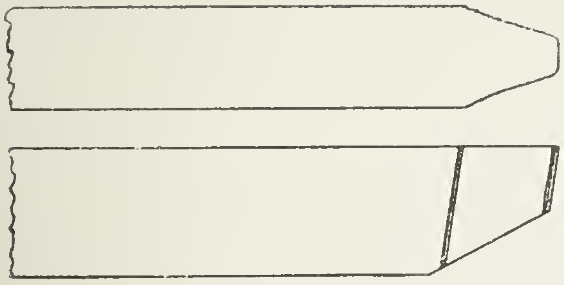

Fig. 5

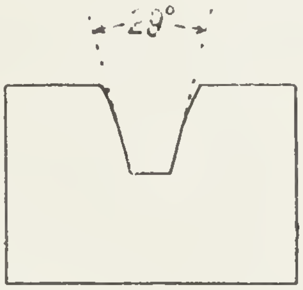

Fig. 6

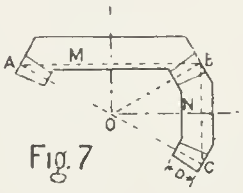

Fig. 7

In making these templates, and also in laying out pattern gears, the curves are struck with a compass. This does not give the true curves, but it is probably as nearly correct as they could be drawn in any other way without special instruments.

Gears, also, may be planed out on a shaper, but not so readily as it is necessary to have some substitute for the dividing head of the gear cutter. There are, however, a number of gear planing machines made by different firms which are used chiefly for heavy gears and for bevel gears. It is usual, I believe, to cast the gears with the teeth in them and to finish the teeth in the machine; for this reason the machines are called gear-dressing machines.

The following is a short description of one form of gear-dressing machine: The dividing head and the mandrel for the gear are much similar to those in the ordinary gear cutter, while the slide for the tool block is at one side of the gear, about on a level with its axis, and is pivoted at a point in front and two or three feet from the gear. The other end of the slide rests on a cam or former, and as the slide is fed up towards the gear the cam gives the required curve to the tooth. By altering the distance between the cam and the pivot, the pitch can be changed. Some gear planers are provided with a circular saw, which can be put in place of the planer tooth for dressing the teeth of mortise gears.

One of the more difficult problems in gearing is that of cutting good bevel gears. These are usually made in pairs, and are intended to run with their axes at right angles and in the same plane; they are the only kind listed in gear catalogues. Where a pair of bevel wheels are the same size, they are called *mitre wheels*. Fig. 7 shows a pair of bevel gears, N is called the *bevel pinion*, M the *bevel gear*, AB is the *largest pitch diameter* of the pinion, BC that of the gear, D is the *face*, O the apex of the two pitch cones AOB and BOC.

In bevel gears the teeth, instead of being on the surface of a cylinder, as in spur gears, are on the surface of a cone, and if the teeth were theoretically correct their elements, if produced, would meet at the apex of this cone. The curve of the tooth, though similar throughout its length, is not the same size or curvature. I do not think I can do better at this point than to quote from Brown & Sharpe's catalogue (p. 161, 1893):

" The curve of teeth in bevel gears, when correctly formed, changes constantly from one end of the tooth to the other. Therefore, bevel gears whose teeth are produced with a cutter of fixed curve are not theoretically correct, the cutter usually being of a curve that will make the large ends of the teeth the correct form, and of necessity leaves the curves too large at the small ends of the teeth. Small bevel gearing is almost universally produced in this manner, which practically answers the purpose, except when the teeth are very coarse or the gears very small, in which cases their operation is not satisfactory.

"In place of cutting by changing the position of the cutter, etc., the teeth are often filed slightly to round them off to the curve required for their free running. On all bevel gears cut with a cutter of fixed curve it is necessary to cut through *twice*, owing to the necessity of making the thickness of the cutter at the pitch line about .005 inch thinner than the space between the teeth at the smallest *pitch* diameter. As the width of space between the teeth at the largest pitch diameter should be greater than the thickness of the cutter, it must be made so by passing the cutter through the second time."

Let us examine the usual method of cutting bevel gears with a rotary cutter. Fig. 8 represents a bevel gear with one cut made through it by a cutter. The cutter is supposed to be central and the slide at zero; that is, the path C, of the centre of the cutter, is in the same plane as the axis of the gear, in which case neither side of the tooth is in line with the apex of the pitch cone. To get one side of the space true, we may either set the cutter a little to one side, or turn the slide through a small angle.

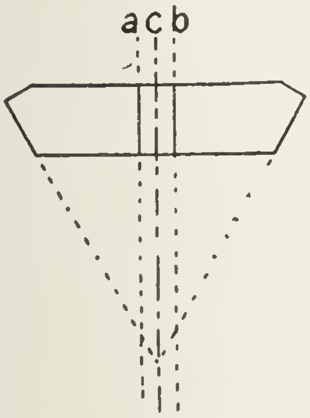

Fig. 8

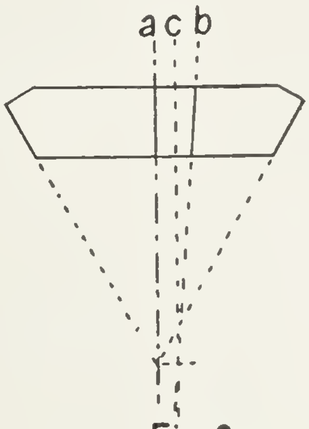

Fig. 9

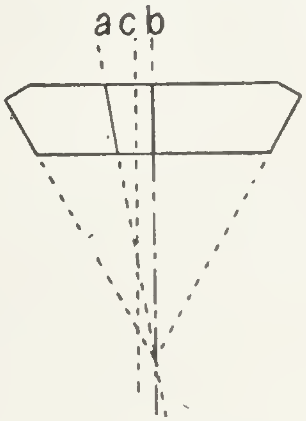

Fig. 10

In the first method we move the cutter to one side a distance equal to half its thickness at the pitch line, revolve the gear in the same direction until the cutter just enters the former cut at the small end of the tooth, and then cut through. This makes side A (Fig. 9) true. We then bring cutter and gear back central and roll the gear and move the cutter to the left, the same as we did before to the right, and cut through again. Fig. 10 shows this cut completed. Both sides of the space will now be true, that is, in line with the apex of the pitch cone, but the space may not be wide enough. The space should be at least as wide as the tooth. If it is not, we may revolve the gear a little more, without moving the cutter over.

In some gear cutters it is inconvenient or impossible to set the cutter over to bring the side of the cutter true, and in that case we may turn the slide through a small angle to bring one side of the cutter true. The gear is revolved as before.

In cutting bevel gears on a universal milling machine, either of the two methods may be used. The position of the cutter being fixed, however, we move the gear, instead of the cutter, to one side, or turn it through an angle.

There is still another point. At what angle (vertically) shall the slide be set? The angle of the pitch cone (COA, Fig. 11) is determined by the ratios of the two gears, the angle of the tops of the teeth, BOA, is a little greater than COA, and the angle of the bottoms of the teeth, DOA, is a little less than COA, by an amount which depends on the pitch of the teeth. The usual practice is to set the cutter to the angle of the bottom of the teeth, although machinists advocate setting the cutter at the angle of the pitch cone.* The reason is more apparent in the case of cycloidal teeth, for, as the faces are usually convex and the flanks concave, the curve changing at the pitch line, if the cutter is the right curve for the large ends of the teeth, and is set at the angle of the bottoms of the teeth (EOA, Fig. 11), then the line where the curve changes will not be along the pitch cone (FO, Fig. 11), where it should be, but along the line FH. This would make the small end of the tooth very bad shape (see Fig. 12). If the cutter slide is set to the angle of the pitch cone, the bottom of the tooth will be along the line EM, which will make the tooth too deep at the small end, but it will be better shape than the preceding.

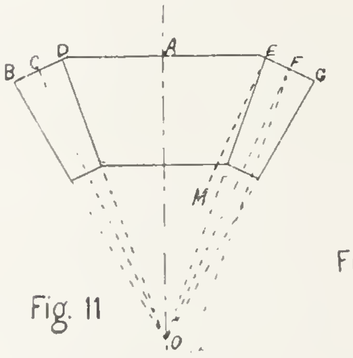

Fig. 11

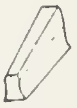
Fig. 12

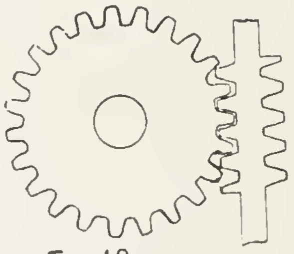
Fig. 13

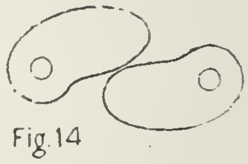
Fig. 14

Bevel gears of coarse pitch are better if cut by some form of planing process. The gear-dressing machine before described is quite suitable for this purpose, as the centre at which the slide is pivoted can be set at the apex of the pitch cone, and every cut of the tool will then be in line with the apex of the pitch cone, and the teeth will be the right curve throughout, provided the curve is correct at one place.

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*_American Machinist_, April, 1892.

Another subject in connection with gearing is that of worm gears. A worm gear and a worm form a sort of combination of a rack and pinion with a screw and nut. The section (Fig. 13) of a worm and worm gear shows the similarity to the rack and pinion.

The worm is turned in a lathe, the dimensions of the threads (in section) being the same as those of a rack. The tool for turning the worm thread should have its sides straight, and the angle between them should be 29 degrees. The width at the point is about two-thirds the width at the pitch line, and the corners are not rounded off as they are in a rack tool.

The worm gear is usually cut in a gear cutter and then "hobbed." The gear being hollow on the face, it is necessary to take what is called a "drop cut," *i.e.*, the cutter is brought under the centre of the gear and the gear fed down upon it. The cutter, of course, is set at an angle (horizontally), the tangent of this angle being the pitch or lead of the worm thread divided by the circumference of the worm. The teeth made in this way have not the real helical form, but for ordinary purposes they do quite well; but to give the teeth the exact form the gear must be "hobbed."

The hob for any worm gear is almost exactly like the worm for that gear, but is made of steel and has longitudinal grooves, a little deeper than the threads, to give it cutting edges. To hob a worm gear, the hob is put on a mandrel between the lathe centres, and the gear on a vertical mandrel in the tool block, where it is free to turn on its mandrel. The hob is put in mesh with the gear and is revolved; it turns the gear around, just as the worm would, and at the same time cuts out the teeth to the exact form required.

The teeth in the worm gear might be cut altogether by the hob; but unless there were some means of revolving the gear at the correct rate, the spacing would not be likely to come out well, although some gear cutters are so arranged that the worm gears can be cut by the hob alone.

There are other methods of making worm gears. Sometimes they are made just like ordinary spur gears, except that the teeth run at an angle across the face; this is called a straight angular cut. The worm has very little bearing surface on a gear cut in this way, yet these gears are said to work quite well, and as they are much cheaper than drop-cut and hobbed worm gears are used to a considerable extent for elevators.

The worm and worm gear of the dividing head of a gear cutter are made differently still. The worm thread is a sharp block V, and the worm gear is straight on the face, is drop-cut and not hobbed, as hobbing might affect the accuracy of the spacing.

Gears are sometimes made other shapes than circular, to give a varying motion. For instance, a pair of elliptic gears may be used to give a quick return. A pair of irregularly shaped gears may be seen at work on one of the large presses of the Methodist Book and Publishing Company of this city. Fig. 14 will give a rough idea of their shape; they are used to give a variable motion to a chain carrier which removes each paper as it is printed and lays it on the pile. The paper is caught by the forward edge, is carried quickly through the air (to keep it nearly horizontal), and is laid gently on the pile.

A practical example of the time required to cut gears might be interesting.

A certain street railway company cut their own motor gears. For the Edison motors which they use, the pinion has 15 teeth and the gear has 63 teeth, both three pitch, 6-inch face. The pinions are made of steel, the gears sometimes of steel and sometimes of cast iron. It takes about three hours to cut a pinion, five hours to cut a cast-iron gear, and ten hours to cut a steel gear. The gear cutter is of the type called half-automatic, and is somewhat antiquated. The results are very good, however, for this type of machine.

Compare this with the results obtained by the General Electric Company at Schenectady. They have five automatic gear cutters similar to Fig. 2, use duplex cutters in them, and each machine cuts from 10 to 13 cast-iron gears, 23-inch diameter, 4½-inch face, 67 teeth, 3 pitch, in 10 hours. A little calculation will show that the metal to be removed in each of these gears is about four-fifths as much as in the 63-tooth gears before mentioned; thus 10 to 13 of the 67-tooth gears would be equivalent to 8 to 10 of the 63-tooth gears, which is four or five times as many per day as the half-automatic machine could cut. As one man could probably attend to the five machines, he would cut from twenty to twenty-five times as many gears per day as the man with the half-automatic machine.

By methods such as these the cost of cut gears can be brought down nearly to that of cast gears.

Toronto, Ont., February, 1895.

DESCRIPTION OF THE FINLAYSON MARINE PIPE BOILER

ARTHUR E. BLACKWOOD, '95.

During the last few years water tube boilers (the reverse of the old style, wherein the water surrounded the tubes, and the heat passed through) have come prominently to the front. Experience has proved the pipe boilers to be economical of fuel, rapid steam generators, lighter in weight and smaller for equal capacity than any other boiler; they have also been proved to be non-explosive under the highest pressure.

In view of the above facts, the writer will endeavor to explain the construction of the Finlayson marine boiler, which has come under his notice during the past year.

The most important point to be considered in constructing water tube boilers is how to build them so as to get the water divided to as great an extent as possible, or, in other words, to get the greatest number of feet of pipe in the space. There is no doubt that Mr. Finlayson had carefully studied this point, as well as the action of heated particles in a liquid, before designing his boiler, as he has embraced in its construction all the advantages of the drop tube boiler without its disadvantages.

He has provided for the ready escape of steam from the generating pipes by placing them in a vertical position, and so connecting them that their water supply is from the bottom, the advantage of this being in not having the water descending and steam ascending in the game tube.

The fronts and backs of water tube boilers, as generally used, are laid up with fire-brick to about three-quarters the height of the boiler, but it is claimed by Mr. Finlayson (and, in the writer's opinion, very justly so) that the use of the brick ends is a mistake, for the following reasons:

I. The heat taken up by the fire-brick is absolutely wasted.

II. The fire-brick walls are just so much dead weight (which is an important consideration in some small boats).

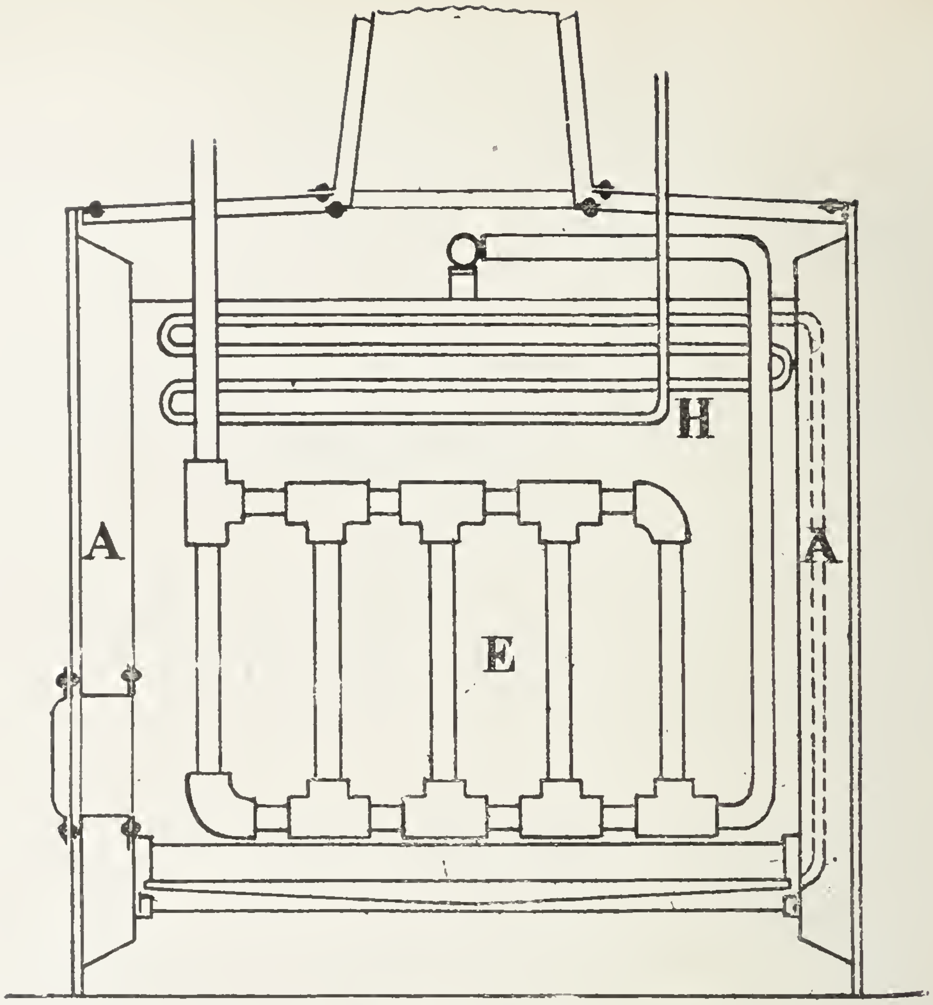

Fig. I.

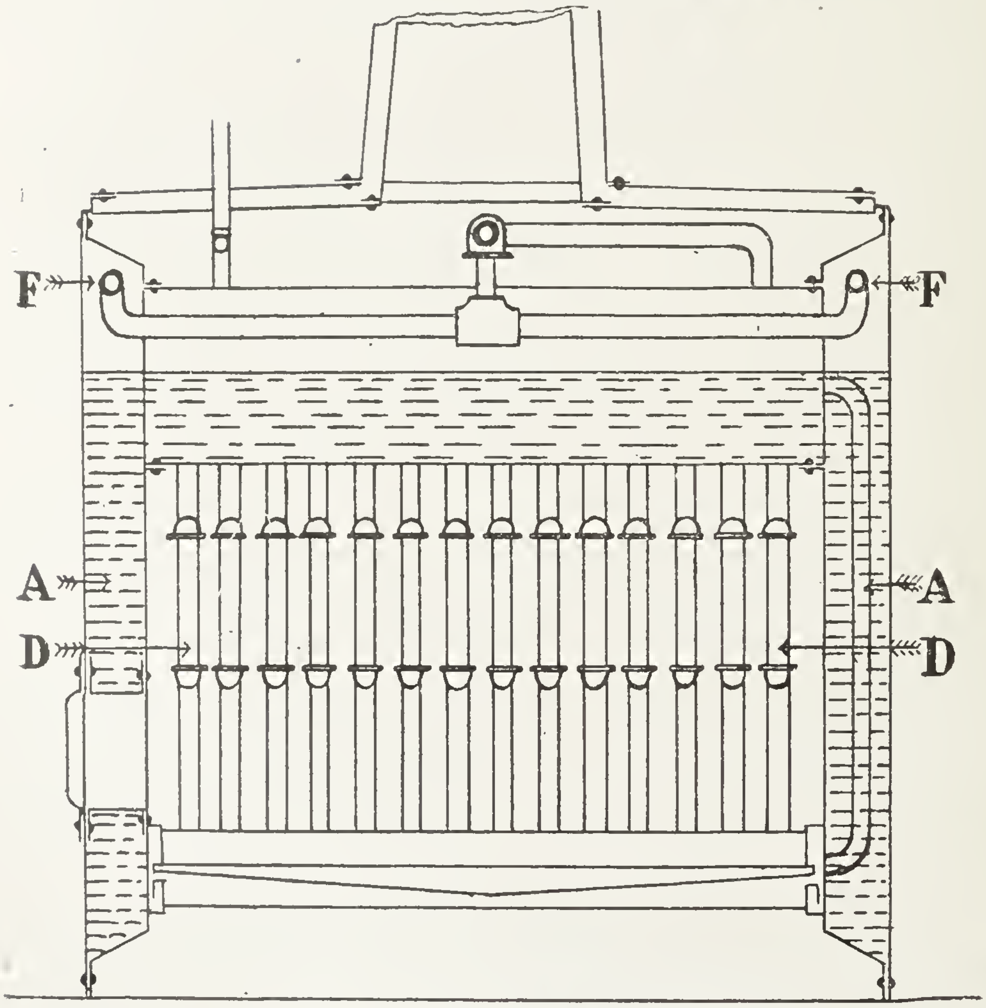

Fig. II.

III. A sudden jar against a pier in landing or a sudden blow from a heavy sea will very often knock the brick wall into the furnace, and thus cause great liability to fire. On account of these objections to the fire-brick walls, and in order to utilize all the heat possible, as well as to secure a greater water space, thus assuring a constant water level, the boiler under consideration is always built with the water front and back, as shown by AA, Figs. I. and II.

The front and back are similar in construction, the outer plates being each cut from a single sheet of steel $\frac{5}{16}$ inch thick, and the inner or flanged plate from $\frac{1}{4}$ inch steel. The flanging is done by heating the plate red-hot to a distance in from the outer edge of about 8 or 10 inches; it is then placed on a flange block, and the required flange made by hammering. The inner plate is then drilled and riveted to the outer one, stay bolts being placed at regular intervals throughout the water space; the object of these being to strengthen the plates, which would, were the stays not used, be forced further apart by the great pressure they have to support.

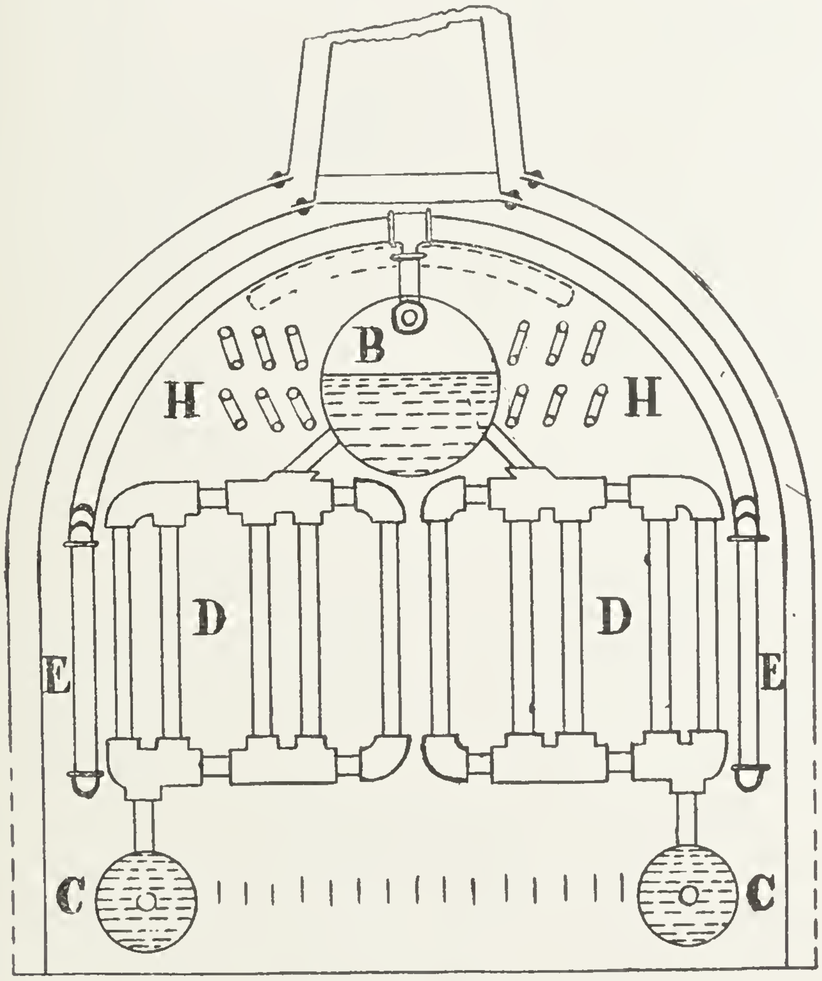

Fig. III.

After the front and back are built, they are fastened together by means of three horizontal steel pipes, which are threaded at both ends and screwed into flanges riveted on the inside sheets. One of these pipes, B, measures 10 inches in diameter, and the other two C, C, 4 inches in diameter. The 10-inch pipe is placed at the top and in the centre of the boiler, the other two being secured one at each side near the bottom, as shown in Fig. III.

The skeleton of the boiler being then complete, the steam-generating loops (D, D, Figs. II. and III.) are made and fitted. These loops consist of five vertical steel pipes connected together by malleable steel castings, manufactured specially for this work. The size of the pipe used in the loops varies according to the power of the boiler, although 1-inch pipe is the average size used.

After the loops are made, they are tested to a water pressure of 400 pounds per square inch before being placed in position in the boiler, the object in testing each of these parts separately being that a defective pipe can be much more easily removed and replaced by a good one before the loop is placed in position than it could be afterwards; besides, caulking at the joints is required in nearly every case, and this could not be done were the loops in their final place. From thirty to forty of these steam-generating loops are used in each boiler, that is, from fifteen to twenty on each side. They are fastened in place by means of vertical right and left hand nipples screwed into the lower side pipes, and by diagonal right and left hand nipples screwed into the 10-inch central pipe.

The next operation is the building and placing in position of the superheating coil. (E, E, Figs. I. and III.) This coil is made of a larger size steel pipe than that used for the generating pipes, and is placed at the side of the boiler and very near the fire. The object of this coil is to catch any water that may come over with the steam, should the boat containing the boiler happen to turn a little on to its side. This water would, of course, fall to the bottom of the coil, and, on account of its close proximity to the fire, be soon turned into steam, and then, rising to the top of the coil, pass off to the engine perfectly dry.

The steam is taken, by means of two bent pipes (F, F, Fig. II.), from as high a point as can be got, and, therefore, starts on its way to the engine as dry as it is possible to secure it at any point in the boiler. It then passes through the superheating coil, already described, and is further dried, so that finally it is received by the engines in a perfectly dry state. It will be noticed, then, that, on account of this coil, it is impossible for water to get into the engine by passing over with the steam.

The feed water coils, as shown by H, H, Figs. I. and III., are now next placed in position, namely, on each side, along the top of the steam-generating loops. This coil is made of a smaller-sized pipe than that used for the loops, and is constructed so as to cause the cold water injected to pass backward and forward five or six times before going into the boiler proper, the water is consequently quite hot when admitted. The feed water is discharged into the lower horizontal pipes, the reason for this being as before stated, that as the heat under the generating pipes causes the steam to rise in them a new supply of water is obtained without it having to come down the same pipe in which the steam is ascending.

The inside of the boiler then being complete, the jacket, or cover, is put on. This cover consists of two sheets of thin steel, packed between with asbestos, and the bottom is a plate of ¼-inch steel.

The necessary safety valves, try cocks, steam gauge, blow-off cocks, water gauge, etc., are then attached, and the boiler is ready for the inspector's test of 400 pounds per square inch.

[Note.—The piping used throughout is a grade of lap-welded steel pipe made specially for boiler work.]

Toronto, Jan. 23, 1895.

SEWAGE DISPOSAL IN ONTARIO

R. W. Thomson, B.A.Sc.

The subject of sewage disposal is becoming of such universal interest that a short sketch of the influences at work and the results accomplished in this direction in our own province may not be out of place here.

For years sanitarians in different parts of the civilized world, more particularly in Europe and America, have heen wrestling with the problem of "sewage disposal" as applied to the requirements of their particular country.

In a new country, where population is sparse and the accumulated wealth is not sufficient to warrant expenditure in the extravagances and refinements, or even the conveniences, of life, the question of sewage disposal is not forced upon the people; but as soon as the population has reached a point of development into towns and cities, so soon do the ordinary laws of health demand artificial means for the removal of the offensive products of civilization from the immediate vicinity of such town or city, and in such a way that its disposal shall not interfere with the rights or privileges of any other place, or even any individual.

In the case of seaport cities the easiest and most economical method is, doubtless, to run the sewage directly to the water, trusting to the diluting and purifying power of this to render it harmless. Even in the case of inland cities situated on lakes or other large bodies of water this method is often the most expedient, if not the most sanitary. However, so eminent an authority as Col. Waring, writing on this subject, says: "So firmly do I believe it to be wrong to wash the organic wastes of our lives into the sea that I should hesitate even to recommend such a course were it not for the greater wrong of keeping them in a putrescible form in the vicinity of dwellings."*

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*"Sewerage and Land Drainage," by Waring.

In the cases mentioned the greatest sufferer from any nuisance that might arise, such as the fouling of its water front or the contamination of its water supply, would be the community itself, and, so long as these unsanitary conditions did not become sufficiently marked as to be prejudicial to the health of the community, no exception should be taken to this method of disposal. But these are not the conditions that obtain in the majority of towns and cities in Ontario, which are situated on a river or other small stream, the pollution of which means the contamination of the water supply of, or the creating of a nuisance to, other places down the stream. This condition involves the question of the consideration of the rights of others, and to such an extent that we would expect to find legislation bearing on the matter. As long ago as 1888, the authority before quoted, writing in this connection, said: "The indications are clear that legislative control of this matter cannot long be delayed, and there is no more intricate or more interesting problem now presented to the sanitarian than the correct solution of this great question of the future." This statement has been strongly supported by subsequent evidence in the way of costly litigation between municipalities and others. Only a few months ago we had a case in point in Ontario, where the municipality of Peterborough issued an injunction to prevent the town emptying its sewage unpurified into the Otonabee River. The courts have not yet decided the matter.

At this date there is in Ontario no statute setting any direct restrictions on the method of disposal or on the quantity or quality of sewage discharged at the outlet, whether that outlet be a lake, river, small stream, or mud puddle. The power of regulating these details is vested in a Provincial Board of Health by the following statute (sec. 30, ch. 205, R.S.O., 1887): "Whenever the establishment of a public water supply or system of sewerage shall be contemplated by the council of any city, town, or village, it shall be the duty of the said council to place itself in communication with the Provincial Board of Health, and to submit to the said board before their adoption all plans in connection with said system.

"It shall be the duty of the Provincial Board of Health to report whether, in its opinion, the said system is calculated to meet the sanitary requirements of the inhabitants of the said municipality, whether any of its provisions are likely to prove prejudicial to the health of any of the said inhabitants, together with any suggestion which it may deem advisable, and to cause copies of said report to be transmitted to the Minister of the department to which the said Provincial Board of Health is attached, and to the clerk of the municipal council, and to the secretary of the local board of health of the district interested.

"No sewer or appliance for the ventilation of the same shall be constructed in violation of any of the principles laid down by the Provincial Board of Health, subject to appeal to the Lieutenant-Governor in Council."

Since, then, all questions of sewage disposal are to be governed by principles laid down by the Provincial Board of Health, it is well to know what those principles as now defined are. At a meeting of the Association of Executive Health Officers of Ontario, held in Trenton, August 20th, 1891, the report of a special committee on sewage disposal was adopted, which contains the following extracts relating to sewage disposal: "That in all places having or constructing systems of sewerage it is desirable that the sewage be delivered at its outfall separately from storm water, in order, among other reasons, that the economical and profitable utilization of it may be possible. Therefore, it is recommended that the separate system or the restricted separate system of sewerage be adopted whenever practicable.

"That the most desirable method of disposing of sewage is by land irrigation wherever this is practicable. This method is especially important for cities and towns situated inland, or on such rivers and streams as are or may be used for public water supplies.

"Inasmuch as it has at times been found necessary (especially in older countries where the land is expensive, and the best land for sewage farms is not always available) to concentrate the sewage, some method of precipitating the suspended organic portion of it has to be adopted.

"In every instance, however, where the town to which sewage disposal is applied is situated on a lake or river whose pollution may possibly affect a public water supply, it is found necessary with every precipitation method to cause the passage of the effluent from the precipitation works to a land area for filtration."

The above defines very clearly the stand at present taken by the Provincial Board of Health, and it is probable the tendency will be to incline to greater strictness as the Province develops.

In France, Germany, England, and the United States, the purification of sewage by application to land has been proved to be a success even in cases where the combined system of sewerage is in operation. There are a few isolated cases where its opponents claim it has been a failure, but, if a failure at all, the failure has been due to carelessness in attendance, or else it has been a case of putting fertilization before purification. It is most instructive to read instances of the purifying power of earth when under favorable conditions. At Gennevilliers, in France, experiments were made to ascertain this power. Large tanks were constructed, filled with earth to a depth of six feet, and underdrained. Sewage at the rate of 24,000 cubic metres per hectare in six months was applied, and out of this only 1,600 cubic metres reached the drains below, nearly $\frac{14}{15}$ being evaporated. The above quantity is equivalent to about 14,000 gallons per acre per day, or at sixty gallons per person per day is equivalent to 232 persons per acre. Of course, this by no means represents the total capacity of the land, other experiments at the same place having demonstrated that in permeable lands the yearly irrigation may reach 100,000 cubic metres per hectare, or, on the same basis as before, 500 persons per acre. At Breslau, where storm water is admitted, the proportion reaches 400 persons per acre.

An idea of the degree of purification reached by fiitration at Gennevilliers may be best obtained by comparing the following results of bacteriological analyses :

Sewage at outlet of main	contained	per cubic cent	20,000	microbes
Water of Seine	"	"	1,200	"
" Vanne (Paris drinking)	"	"	62	"
Rain water	"	"	35	"
Underdrainage of Gennevilliers	"	"	13 to 24	"

An extensive series of experiments in sewage purification has been also carried on at Lawrence, Mass., under the direction of the Massachusetts State Board of Health. Space will not permit of our going into the details of these experiments, but we may note some of the conclusions to be deduced from them, which are :

(1) In order to get the best results, it is imperative that the sewage be applied to the land intermittently.

(2) That the capacity of earth to purify increases with use, under proper conditions, up to a maximum depending on the quality of the soil.

(3) That the application of sewage to land is at present the only practicable method of purification.

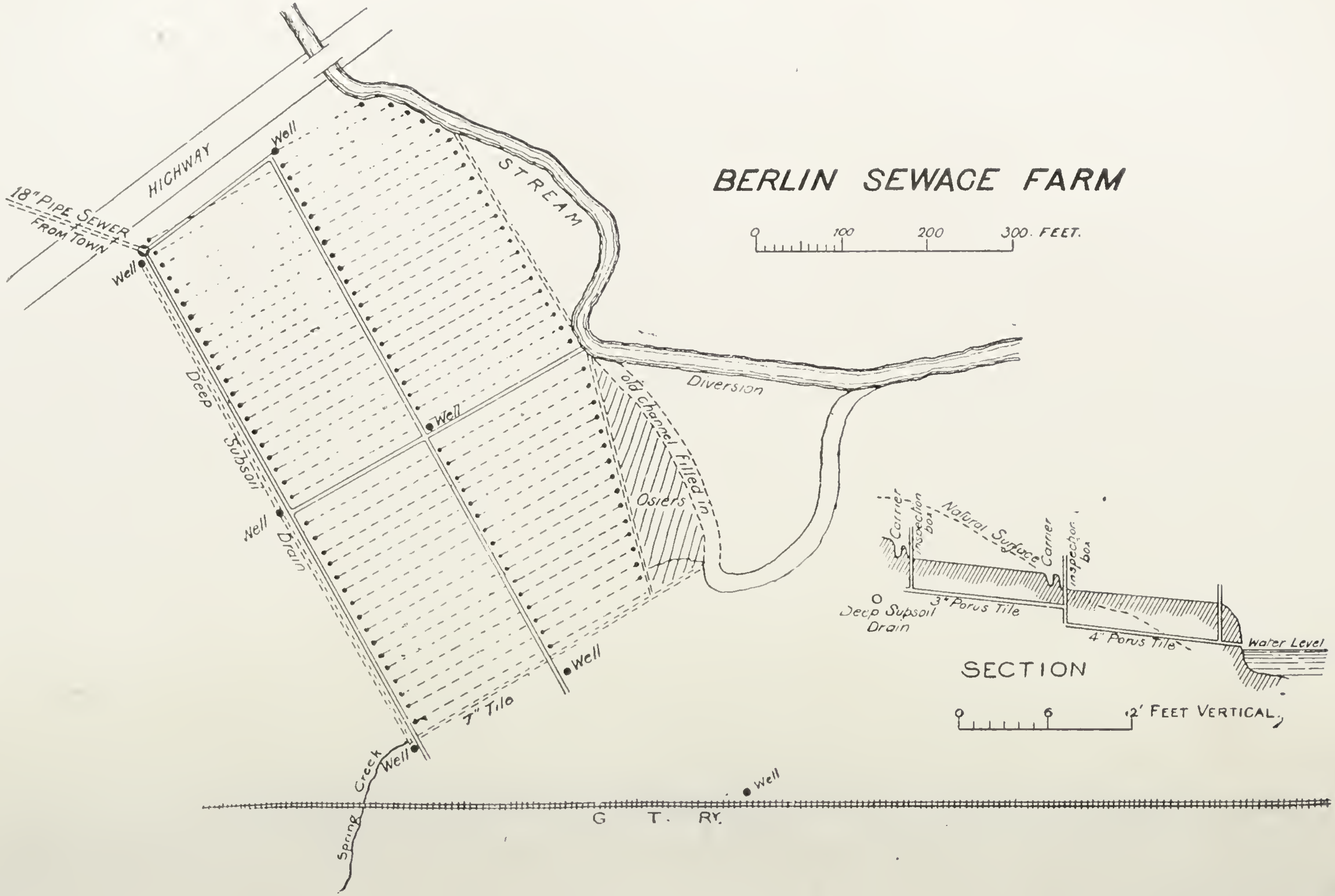
(4) That the process of purification is due to the work of minute organisms in the soil, which convert the organic matter of the sewage into harmless inorganic substances capable of sustaining plant life.

(5) That the process of nitrification or purification goes on between 32° and 130° Fahr., and is most active at about 100° Fahr.

In one experiment the necessity for intermittent application was shown most conclusively. While acting intermittently the filter removed 99.2 per cent. of the sum of the ammonias in the sewage, but when kept continuously saturated the sum of the ammonias in the effluent gradually increased until they exceeded those in the sewage, some of those previously stored in the filter escaping. The sewage was then applied intermittently as before, when the nitrates in the effluent began to rise, until they exceeded the ammonias in the sewage by fifty per cent., the impurities collecting during the continuous filtration becoming nitrified. After three months the effluent was again purer than the average drinking water of the state. In each case the amount of sewage treated was the same, the difference in purification being entirely due to the different methods of treatment. In speaking of the purity of the effluent treated by intermittent filtration, the amount treated being from 117,000 gallons to 60,000 gallons per acre, the report says: "We have found that the sum of the ammonias which have been taken to indicate the amount of nitrogenous organic matter has been reduced to 0.5 of one per cent. of those in the sewage, and is less than the sum of the ammonias of most of the public drinking water supplies of the state." One result of these experiments has been to bring the question of sewage purification more forcibly before the people, and to demonstrate, in response to the constantly increasing demand for some system of sewage purification, that the only practicable method where purification, and not simply clarification is required, is to apply the sewage to land.

The stand taken by our Provincial Board of Health, together with the interest that is being aroused in local sanitarians, due to the imperative demand of our increasing population for some practical and economical method of sewage disposal, is being already felt.

We have at present only two filtration areas on any large scale in Ontario—one in connection with the Asylum for the Insane, London, and the other the Berlin sewage farm. Plans have also been prepared for a system at Waterloo, where the work is partly finished. Guelph and Galt are considering the putting in of sewerage systems, and will probably have filtration areas in connection. The system at the London Asylum was designed by Col. Waring, and is the Intermittent Downward filtration system. The sewage from the different buildings is collected in a large tank constructed of brick and lined with cement, having a capacity of rather more than 100,000 gallons. From the tank the sewage is pumped by a six-inch rotary pump to the filtration area, through an eight-inch spiral riveted steel pipe about 1,550 feet long. The filtration area comprises



BERLIN SEWAGE FARM

about four acres, laid out in eighteen parallel ditches eight feet wide at top, two feet wide at bottom, and one and one-half feet deep, separated by beds ten feet wide at top. The bottoms of the ditches are all in the same horizontal plane. The sewage is conveyed to these by an eighteen-inch vitrified channel pipe running from the distributing well at one corner of the field in a line at right angles to the settling ditches, and connected to them by **T** channel pipes. The sewage can be turned into any one or all of the settling ditches at will, or can be all diverted to the broad irrigation tract below by inserting small wooden dams at different points in the carrier.

In reply to some questions on the working of the plan, Dr. Bucke, the superintendent of the asylum, writes: "Sewage disposal at this asylum is on what is called the Intermittent Downward filtration system. We use four acres of land for 1,200 persons, and it is ample. The system has been in use here five years, and has given the most complete satisfaction. The coldest weather gives us no trouble. The sewage in the tank never reaches a temperature lower than, say 50°, and when thrown into the trenches thaws the ground enough to let it through. We never see the effluent, and so know nothing about it; no doubt it again reaches the surface somewhere as *spring water*, and, no doubt, it is *pure spring water*.

"Using the sewage to irrigate, I grow on the beds between the trenches (*i.e.*, on about two acres of land) a crop worth from about $800 to $1,000 a year. The system is not only economical, but, I am satisfied, could be made to pay enormously if properly carried out for cities, towns, and villages."

The plant at Berlin was designed by Mr. Willis Chipman, C.E., and superintended by Mr. H. J. Bowman, town engineer. The system is Broad Irrigation. There are about twenty acres in the farm, only eight having been graded and underdrained. The sewage in this case is not collected in a tank, but runs directly to the irrigation tracts. These tracts are graded and underdrained to a depth of from three to four feet, this being the maximum attainable on account of the insufficient elevation of the tract above the watercourse into which the drains discharge. The drains are of agricultural tile, in parallel rows sixteen and two-thirds feet apart. Inspection boxes, six inches square, made of plank, are situated at each end and at the middle of each drain. Small wells have also been dug at different points on the farm for the purpose of observing the height of the subsoil water. The farm has been in operation since 1892. Writing under date of January 23rd, 1895, and referring to the Berlin farm, Mr. Bowman says: "This method works very well except in winter, when, on account of the beds having a fall away from the carrier, the sewage runs across the surface in channels.* During the past summer we have added new ends perfectly level."

Mr. Bowman has kindly sent me a plan of the proposed works at Waterloo, accompanied by the following description : "These beds are about 200 x 132 feet, perfectly level, and separated by embankments formed from the top soil. Tile drains will run across the beds and only ten feet apart, and vary from three to four feet below the surface. This depth is not sufficient to give the best results, but is enough for partial purification, which is all that is required, as the stream receiving the effluent is not used as a water supply."

The great objection to the adoption of sewage disposal by application to land in Ontario seems to be the idea that our climate is too severe in winter for the proper working of such a system, an objection more fancied than real, as the unqualified success of the plant at the London Asylum has demonstrated. The Berlin system must also be considered a success, since it is being followed by a similar one at Waterloo. However, it is only by trial that the details of the system best adapted to the varying conditions of our climate can be discovered. There is no doubt that the success of the London farm is in part due to the exceptionally favorable nature of the soil, but there is also reason to believe that a great element in its successful working in the winter season is the fact that the sewage is collected in a large tank and then discharged over the filtration area before it has time to become very much lowered in temperature, the amount of heat in the liquid due to its temperature above the freezing point being sufficient to thaw the ground and admit of its uniform filtration through the soil, and, were this point in detail adhered to in all cases instead of letting the sewage dribble over the soil as it comes from the outlet, there would probably be less cause to think that our Ontario climate in winter is too severe for successful sewage disposal by land application.

Toronto, March 5th, 1895.

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*For some reason the beds were constructed with a greater slope than intended by the designer. —R.W.T.

POWER SWITCHBOARD AND DYNAMO TENDING

Robert A. L. Gray, '95.

If any of you expect, under the above title, a learned discourse on this subject, I fear you will be greatly disappointed ; I will merely attempt to give a short description of the construction of a switchboard at which I worked, and, perhaps, give a few hints which may be of benefit to beginners.

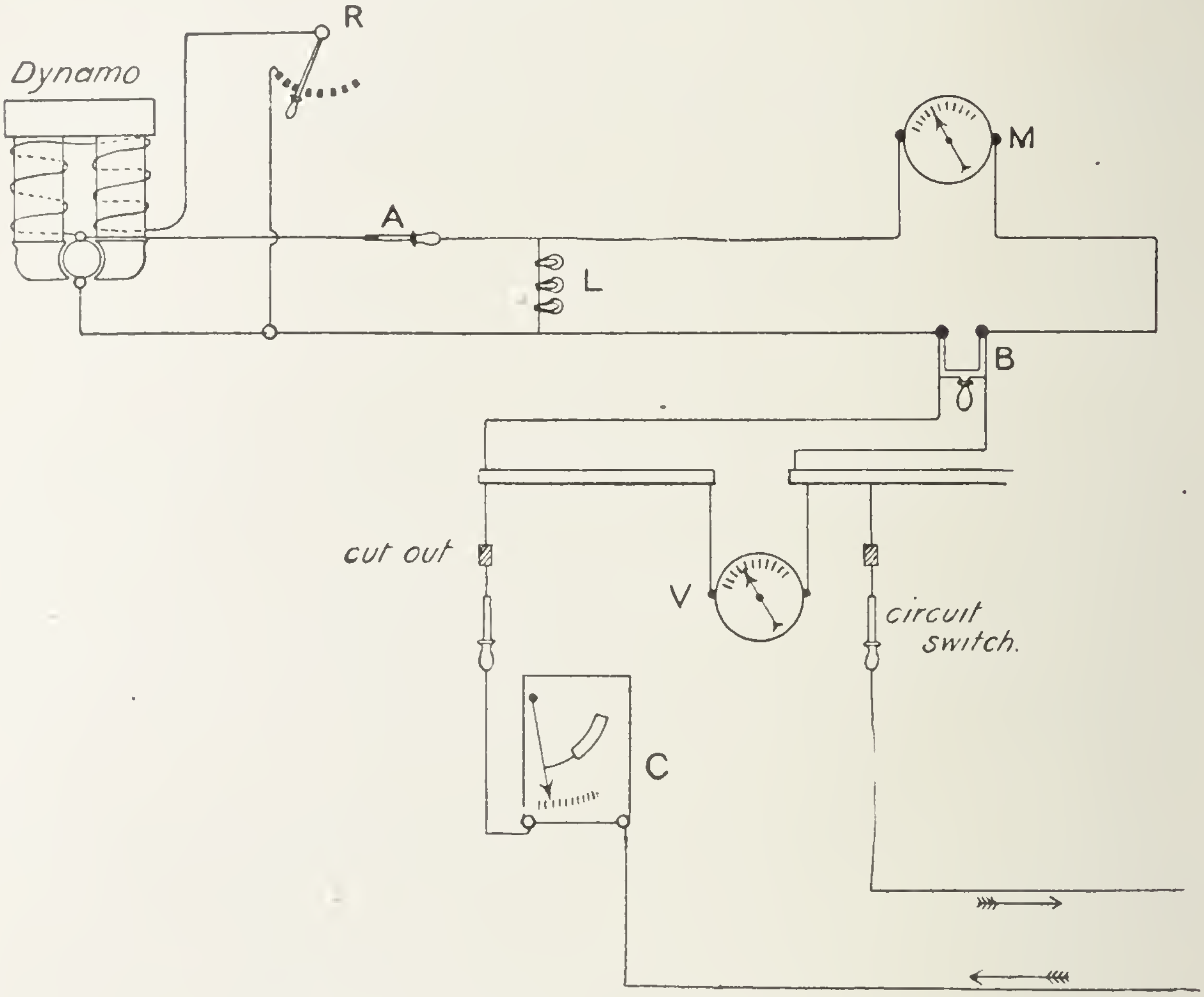
The switchboard was for the purpose of regulating six compound wound dynamos supplying power to motors for printing presses, elevators, etc.

These dynamos were connected in multiple, the positive and negative brushes being connected, respectively, to two heavy copper bars fastened to the switchboard.

The diagram shows the connections for a single machine, and the connections for one of the outside circuits. It will be seen that each machine has three incandescent lamps, L, in series with each other, across its terminals, and also that the dynamos, which are compound wound, are regulated by the Edison system, a rheostat being inserted in the shunt circuit to regulate the amount of current flowing through it. In series with each machine is also a single switch, A, and an ammeter, M, while, between the two copper bars is a voltmeter, showing about 250 volts between its terminals. The voltage of the test lamps will, therefore, aggregate 250 volts.

Leaving the dynamos for the present, we shall proceed to the outside circuits. There are five of these connected in multiple, each circuit having two switches, an ammeter, and two cut-outs in it. The switchboard, behind which a passage is left to allow of renewal of wires, etc., is a wooden framework with a shelf running along it, the switches and cut-outs on the board being mounted on slate and porcelain to obviate all risk of fire. In my opinion, it is best to have an open switchboard like this, because all the wiring is then in sight.

The ammeter C, for indicating current in the outside circuit, is of a very simple and effective type, and consists of a coil of very heavy insulated copper wire with a small armature connected to the index finger, which is pivoted at one end. The armature is pulled into the coil, a distance proportional to the current flowing, thus causing the index to move along a graduated scale.



WORKING IN A DYNAMO.

This operation must be performed with considerable care, or trouble is sure to result. First, put in the single switch and let the dynamo run for a little while, when the test lamps will gradually grow brighter and brighter, the resistance in rheostat being regulated until lamps are of proper brilliancy, showing that machine is developing a proper EMF. Test this also with the double switch. If a fairly large spark is made when this switch is closed a little and then opened, the machine may be safely worked in, and the switch be completely closed. The voltage and current to be given by each machine are now regulated with the rheostat, care being taken that each dynamo has, at least, enough to do, otherwise it will stop giving current, and then, suddenly, a current in the opposite direction will be produced, which is, of course, sure to make trouble. This dropping out and reversing is most liable to occur when the load is light, as at noon. Then all the factories will be closed down, and almost the only current taken from the mains will be that used for elevators, a current necessarily varying greatly, as a large amount will be taken off for a few moments, then this will suddenly drop to almost nothing when, the load being nearly all taken off the dynamos, they will tend to drop out and reverse. Of course, if there were only one dynamo running, this would not matter so much, but two are usually kept going at noon, so as to relieve each other.

TAKING OUT A DYNAMO

In taking a machine out of circuit gradually shift the load on to the other machines, and then, just when there is no current shown on the dynamo ammeter, open the double switch and slacken down the engine, then open the single switch.

If an accident happens to any of the machines, and the others are not able to supply the whole demand for current, so that one of the outside circuits has to be opened, be very careful which circuit you do open. For instance, if a machine supplying only a *small* amount of current has to be taken out, do not open an outside circuit, taking a *lot* of current, as the effect of this would be that the other machines would not have enough work to do, and would therefore commence to drop out and reverse. I believe switches are now being made which open when less than a proper amount of current is being supplied, and this will, of course, obviate a great deal of the trouble referred to.

Above all things, keep your wits about you, and, if any accident happens, be prepared to act promptly, so as to remedy the trouble as well as possible. I found it a good habit, while the load was steady, to think of what I should do in case of accident, and so was usually prepared.

CARE OF A DYNAMO.

Be sure always to keep the machines clean. This should always be attended to the first thing in the morning, when all oil and dirt should be carefully wiped off the base and other parts, for although the oil itself is not so injurious, yet it holds dirt, copper dust, etc., which is very liable to produce a short circuit. See that there is plenty of oil in the bearings and that the commutator is bright and clean, occasionally lightly swabbing it with oil of a character depending upon the material of which the brushes are made, castor oil being the best for copper brushes, as it does not make the commutator sticky or gummy. Always keep the brushes perfectly clean, and if of copper clip them quite often, to keep a good edge on them. This edge should be bevelled at an angle of about 45°.

The ordinary copper brush with which I had to do I shall now describe. It is usually made up of several thin sheets of copper placed together and folded in the middle, with a heavier piece over the top, the whole being then either soldered or riveted together. This makes a fairly flexible and springy brush, but it is very dirty, for the commutator, rubbing against it, wears the copper off and sends it flying in all directions. This dirt has to be all cleaned off, and takes considerable time, as the dust gets into any corners or chinks in the machine, and has to be got out with bellows and brushes. Another disadvantage of this brush is that, if anything should happen to produce sparking, the layers of the brush get fused together at the ends, necessitating clipping, which, besides taking considerable time, is very wasteful. In a certain large lighting station it takes two men working all day to clean up machines and clip the brushes, whereas one man could easily do the work of cleaning the machines. On the whole, I think carbon brushes are much to be preferred.

Slipping of belts is often a great source of trouble, and is sometimes caused by oil getting on them. This may often be remedied by throwing a little powdered resin on to the slack side of the belt just at the pulley. A new style of belting is now being advertised which has grooves running lengthwise of the belt, which are supposed to allow the escape of air sufficient to overcome the air-cushion, and thus allow the belt to be run very slack, as well as relieving a good deal of strain on the bearings. This belting should be of great benefit if it fulfils all that its manufacturers claim for it.

In concluding, I would say, never use sheet-iron oil cans. They are sure to cause trouble, and are very liable to get drawn in and caught in the armature when oiling the bearings, with results which I need not try to enumerate.

DYNAMO DESIGN

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The following paper is prepared in the hope that it may be a help to those engineering students who for the first time propose to consider the subject of designing a generator or motor for a specific purpose. It was suggested by the difficulty I myself had at first in picking out a definite path to follow in the labyrinth of principles and applications, of formulæ and usages, of electrical and mechanical considerations that appertain to the subject.

In the limits of this paper I cannot hope to give more than an outline, but my attempt shall be to provide a framework which any one who wishes to go fully into the subject may fill out for himself. There are a good many works written specially on this subject to choose from, but most of them are devoted to the design of particular machines, and would, therefore, not give sufficient help to design one for any purpose. For the engineering student Prof. S. P. Thompson's work is of great value, while the articles by Houston and Kennelly, and by Wiener in the *Electrical World*,* deserve special mention, the former on account of the clearness with which the principles are followed out in accordance with the most recent modes of considering them, and the latter on account of the results of examination and tests of actual machines of many types embodied in them.

In designing a dynamo, there are so many variables for fixing which a good deal of latitude is allowed that the great difficulty one has at first is to know how to adjust them, for the arbitrary fixing of the first may affect all that follows. One may be familiar with the general electrical principles, and yet will find himself at sea when he asks himself where he

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*Electrodynamic Machinery, Houston and Kennelly ; *Electrical World*, Vols. xxiv. and xxv. Practical Notes on Dynamo Calculation, A. E. Weiner, *Electrical World*, Vols. xxiii., xxiv., xxv.

should begin, and whether he should settle one point before or after another. He feels the need of sufficient experience to enable him to decide these points—to select the best forms for a given purpose, and to know what allowances to make for points of secondary consideration, upon which points, however, the special value of the machine mainly depends. We have to consider fundamental principles, but we have also to consider the way of applying them to produce the most economic result. There are, to borrow from chemistry, the qualitative and the quantitative divisions of the work.

Let us now run over briefly the theory of the generator and motor, and afterwards consider the procedure in design. And if I start at the very beginning, it is because I believe that we cannot emphasize too much the importance of carrying in mind the connections between the definitions and axioms of a subject and the main deductions that follow from them.

THEORY OF THE DYNAMO.

1. As satisfying the results of numerous experiments, the following law is accepted as an axiom in the science of electricity:

The strength of field at any point due to an elementary length of conductor carrying current is inversely proportional to the square of the line joining the point and the element, and is directly proportional to the resolved part of the current in the conductor at right angles to that line. The direction of the magnetic force is at right angles to the plane of the element and line, and the sense is given by the familiar rule of the right-handed screw.

2. On this is based the definition of unit current*: *A current has unit strength (C.G.S. unit) when unit length (centimetre) of its circuit bent into an arc of unit radius exerts unit force (dyne) on unit magnet pole placed at its centre.* 1 ampere$=10^{-1}$ C.G.S. units. And from this:

Unit quantity of electricity is that quantity which is conveyed by unit current in one second. 1 Coulomb$=10^{-1}$ C.G.S. units.

Unit difference of potential or electromotive force, since potential is measured by work done on unit quantity of electricity, exists between two points when it requires the expenditure of unit work (erg.) to bring a unit of +ve electricity from one point to the other against the electric force. 1 volt $= 10^8$ C.G.S. units.

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*These definitions are taken almost verbatim from Professor S. P. Thompson's Elementary Lessons in Electricity and Magnetism.

Unit resistance by the aid of Ohm's law is defined from unit current and unit EMF. 1 ohm $= 10^9$ C.G.S. units.

3. From the definition of unit EMF we deduce that a unit current (that is, a unit quantity of electricity per second) does unit work per second in a conductor between points at unit difference of potential, and from this the work done in any conductor per second is the product of the current flowing and the difference of potential between the points considered.

1 C.G.S. unit current × 1 C.G.S. unit EMF $= 1$ erg per sec.
10^{-1} C.G.S. units " × 10^8 C.G.S. units " $= 10^7$ ergs per sec.
1 ampere × 1 volt $= 10^7$ ergs per sec.
i.e., 1 watt $= 10^7$ ergs per sec.

Now, since 1 horse power $= 745.94 \times 10^7$ ergs per sec., it must also $= 745.94$ watts, or 746 watts commonly used in practice.

$$\mathrm{CE} = \mathrm{P} \ (\textit{power})$$

Where the transformation of energy in a conductor is entirely into heat, we have $\mathrm{E} = \mathrm{CR}$ where R is the resistance between the points at difference of potential E, so that the equation for power is

$$\mathrm{C}^2\mathrm{R} = \mathrm{P}$$

the rate of production of heat, or the energy expended per second in heating the conductor.

4. The application of these principles to the theory of the dynamo and motor is this: If E is the total EMF generated in the armature of a dynamo, and C the armature current at any time, then $\mathrm{EC} = \mathrm{P}$ the total power of the machine at the time. Any heat losses in the windings of the machine may be considered just as they would be if the energy were being used in the external circuit, armature and series field coils as in series circuits, and shunt fields as in parallel circuits. Following is a summary of the distribution of power in the generator and motor. The Roman letters are for the generator, the italic ones for similar quantities in the motor.

GENERATOR.	MOTOR.
$\mathrm{EC} = \mathrm{P}$ total transformation mechanical to electrical.	$EC = P$ total transformation electrical to mechanical.
$\mathrm{EC} - \mathrm{C}^2\mathrm{r} =$ power given outside armature and series field.	$EC + C^2r =$ power received in armature and series field.

GENERATOR.	MOTOR.
$EC - C^2r - c_1^2r_1 = E_1C_1$ power given external circuit.	$EC + C^2r + c_1^2r_1 = E_1C_1$ power received from external circuit.
$\frac{E_1C_1}{EC}$ electrical efficiency of generator.	$\frac{EC}{E_1C_1}$ electrical efficiency of generator.

E_1 and C_1 and E_1 and C_1 are the EMF and current, as measured at the terminals of the generator and motor, respectively :

$$E_1 = E - Cr \qquad\qquad E_1 = E + Cr$$

5. *A unit magnet pole is one which placed at unit distance (centimetre) from an exactly similar one repels it with unit force (dyne).*

A magnetic field has unit strength ($\mathfrak{H} = 1$) at a given point when it acts upon unit pole with unit force at that point. *A unit line of force is therefore defined as having unit area of cross section in unit field.* With field strength $\mathfrak{H}$ the cross section of unit line becomes $\frac{1}{\mathfrak{H}}$. As there is unit field at unit distance from unit pole, there will be 4π lines from unit pole and $4\pi m$ lines from pole m.

6. From the first fundamental statement of the relations between a current and its magnetic field (sec. 1), we deduce, by a simple process of integration, the distribution of the magnetic field about a straight infinite current. $\mathfrak{H} = \frac{2C}{r}$ where C is in C.G.S. units current, and r is the distance of the point considered from the wire in centimetres.

If unit pole is carried in a circle around the wire, therefore, by the action of the current, the work done by the current will be

$$\mathfrak{H}L = \frac{2C}{r} \times 2\pi r = 4\pi C.$$

The work is seen to be independent of the radius of the path, and, as no work is done in carrying the pole to or from the wire, a little consideration will show that if the pole is carried in any path whatever around the conductor, if it start and end at the same point, the work will be the same.

7. In carrying the pole around the conductor, all its lines cut the conductor, so that the pole has $4\pi C$ units of work done upon it by the current while its 4π lines are cutting the conductor; or, if a pole with one line or strength $\frac{1}{4\pi}$ were carried around, the work would be C for the cutting

of one line. Now, the circuit does C units work on the pole in virtue of the product CET, where E is an EMF, which would have to be added to that of the circuit to maintain C constant. E, therefore, when T is one second, must also be unity to give total work C. The EMF, added to that of the circuit must be to counteract an EMF due to the cutting of the line through the circuit, since the current remains as before. It is, therefore, the natural inference that the line, in cutting the circuit in a second in the direction it does, produces a unit EMF in a direction opposed to that of the current.

This induced EMF is seen also to be independent of the magnitude of the current, and exists, therefore, when the current is zero, or becomes negative in sign, that is, reverses direction. In the latter case, the pole does work on the electric circuit, *i.e.*, increases the product EC in it.

From the above, we may deduce that the cutting of a conductor by unit line in one second (or of a unit line by a conductor) produces unit (C.G.S.) EMF, and by noting the directions of the magnetic lines, conductor, and motion of the lines or conductor, we may deduce Fleming's rule of the hand for determining their interrelation with the direction of the induced EMF.

8. The generator and the motor are the practical embodiment of the above principle. In both EMF is generated by conductors cutting magnetic lines, for the conductors of the armature cut through the magnetic lines of the field.

If a conductor in one second cuts unit line, it produces unit EMF.

If a conductor moves with unit velocity in unit width of unit field, it produces unit EMF.

If a conductor moves with velocity v in width l of field $\mathfrak{B}$, it produces EMF, $vl\,\mathfrak{B}$, and

If c of these conductors are united in series, the total EMF is $cvl\mathfrak{B}$, and in volts

$$E = 10^{-8} cvl\mathfrak{B}.$$

This is the equation for the EMF produced in the armature, whether of generator or of motor. As $\mathfrak{B}$ is directly proportional to the square of the linear unit, v, l, and $\mathfrak{B}$ may be taken either all in C.G.S. units, or all in the English system.

9. We now come to consider how the magnetic lines are produced. We have a field of average strength $\mathfrak{B}$, and cross-section S to provide, or a total flux $\phi = S\mathfrak{B}$—

As the work done by a circuit on a unit magnet pole (or *vice versa*) depends only on the current in that circuit and the EMF generated by the lines from the pole that cut the circuit, if all these lines cut the circuit once, then the work done is independent of the form of the circuit. So that the work done when unit pole is threaded through a loop with current C, and brought outside and back to the starting point, so that all its lines have been cut once, is 4π C units (the same as that given for the straight current in section 5); and if there are N loops each with current C through which the pole is threaded, then the work is 4π NC units. Furthermore, since $\mathfrak{H}$, the magnetic intensity or magnetizing force at any point of the field, is the force acting on unit pole at that point, the work done in carrying unit pole around the circuit is evidently equal to the line integral of the magnetizing force for the path pursued.

$$4\pi NC=\int\mathfrak{H}dl.$$

10. Now, by definition the magnetic permeability $\mu=\frac{\mathfrak{B}}{\mathfrak{H}}$

$$\text{so that } \Phi=S\mathfrak{B}$$

$$=S\mu\mathfrak{H} \text{ for any cross section of a magnetic circuit}$$

$$\text{or } \frac{\Phi}{S\mu}=\mathfrak{H}$$

and taking the line integral of this around the magnetic circuit, we get (as Φ is constant for all cross sections, and μ and S may vary)

$$\Phi\int\frac{dl}{S\mu}=\int\mathfrak{H}dl, \text{ and this becomes}$$

$$\Phi=\frac{\int\mathfrak{H}dl}{\int\frac{dl}{S\mu}}$$

which is the law for the magnetic circuit corresponding to Ohm's law for the electric. Φ is the total flux, $\int\mathfrak{H}dl$ is the magnetomotive force, and $\int\frac{dl}{S\mu}$ is the reluctance. We have shown that $\int\mathfrak{H}dl$ is equal to 4π NC (sec. 9), and, as magnetic circuits, as a rule, are made up of sections of length l, and constant cross-section S, throughout which the permeability μ may also be considered constant, we may write the equation in the form

$$\Phi=\frac{4\pi NC}{\Sigma\frac{l}{S\mu}} \quad \text{(all C.G.S. units)}$$

11. As the question with us now, however, is how to produce the required flux, the equation takes the form if C is in amperes

$$NC = \frac{10}{4\pi}\Phi \ \Sigma \frac{l}{S\mu}$$

and if l and S are in inches it becomes

$$NC = \frac{10}{4\pi \times 2.54}\Phi \ \Sigma \frac{l}{S\mu}$$

where NC is the number of ampere turns required to produce the flux Φ in the circuit defined by the terms l_1, l_2, l_3, etc., S_1, S_2, S_3, etc., and μ_1, μ_2, μ_3, etc. The magnetic properties of the materials used in the circuit must be known in the forms of curves or tables, giving the relation between two of the three quantities $\mathfrak{B}$, μ, and $\mathfrak{H}$, so that to determine μ for any section we have only to determine $\mathfrak{B} = \frac{\Phi}{S}$ for that section. The relation between N and C can be settled for any particular case.

PROCEDURE IN DESIGN.

12. To understand the foregoing principles of the dynamo, one needs only a slight acquaintance with the actual machine; but to apply these principles to the synthetic process of design or construction, he needs a very practical acquaintance with the make-up, in detail, of such machinery. The best training for this work is to be employed in turn in the different departments in works which build a good type or types of machines, to perform every operation possible in their construction, and to test them when completed. This experience should be supplemented in the repair shops, for there the weaknesses and defects of machines are soon made apparent. This is an invaluable training, if one is careful to understand the reasons for everything that he does or sees done.

Failing this, one should make himself acquainted with the best practice by studying the points of difference of several good types of machines; by partially dissecting them, if possible, to obtain the data necessary for recalculating them and comparing the results of calculation with actual results; and by obtaining access to machinery in process of construction or repair, and paying strict attention to the details of the work.

Tabulated results of best practice will be found of very great help in design.

13. Before proceeding with the design of a dynamo, it is evidently necessary to ascertain as definitely as possible what is required of it. It is to be built for a given purpose. It is a generator, perhaps to do lighting or electro-plating, or to supply a power circuit, or it may be a motor to run a fan, a lathe, or a workshop, an elevator or a street car; a generator for a constant, or for a variable, pressure circuit; or a motor for fixed, or for variable speeds. We must obtain sufficient data for deciding:

(1) What circuit is it to supply or be supplied from?

(2) What power is required of it?

(3) What are the general conditions of use—such as the position that it is to stand or be suspended in, the limit of floor space, protection from dust, water, iron filings, and other sources of injury, the mode of driving, etc.

14. From the answer to the first question, we determine one of the factors of the power. It will decide the pressure to be obtained between the terminals if for parallel working, as for incandescent lighting, and for motors on constant pressure circuits, or the current to provide for in series circuits, as for arc lighting, and for motors on constant current circuits; it will help us in settling the question of open or closed coil armatures, and of series, shunt, or compound fields. The degree of constancy necessary in the pressure of generators and in the speed of motors will determine whether they are to be shunt or compound wound. We shall know also whether special design and regulation will be necessary to effect alterations of EMF in generators, or of speed in motors.

From the answer to the second, we determine the other factor of the power, for, as we know (sec. 3), electrical power is the product of current and EMF, and we have only to divide the required power—reduced to Watts—by the one given to obtain the other; usually, we are given the pressure and require to determine the current to be allowed. As we have before seen, power is lost in the various windings of a dynamo, so that this also must be considered. As to the effect of the power of a machine on the type, one may say, generally, that, for small powers, bipolar machines are preferable on account of their simplicity and economy in construction, while, for large powers, multipolar machines are most economical.

The answer to the third question will affect the general design, particularly the selection of the type.

15. There is an almost endless variety of different types of continuous current machines; they may all, however, be classed as bipolar and multipolar. The bipolar machines may be divided into those having single

or multiple magnetic circuits, and these, again, as having one or more exciting coils. Multipolar machines, in practice, never have more than one magnetic circuit per pair of poles, and often this is abridged; that is, two or more pairs of poles may have parts of their circuits in common. Multipolar machines may, therefore, be classed as having one exciting coil —half as many coils as poles, or as many coils as poles, etc.

16. The common types of armature are the drum and ring (Gramme). In bipolar machines for small armature diameters, the drum winding is the more economical in length (*i.e.*, resistance) of conductor, and the core more simple in construction; while, for large diameters and shorter cores, the ring type gives more economy in metal and winding, and offers much better opportunity for ventilation. Ring winding is done in distinct sections, so that it is much easier to insulate it and replace portions of it than in the case of drum winding, in which the sections all overlap. In ring winding there is one active conductor in each loop; in drum winding there are two.

In multipolar machines, both rings and hollow drums are used; and for these we have the ring, and lap and wave windings, with as many parallel circuits as poles, excepting for wave winding, for which there are always two. The cores of armatures may be smooth or slotted, the advantage, on the whole, lying with the smooth surface. The teeth in the slotted core form good driving horns, and somewhat decrease the magnetic reluctance of the circuit; they also allow the heat to escape more rapidly from the core, but their additional cost of construction, the heating of the pole pieces, due to their unequal distribution of magnetism, and the trouble they cause in sparking, tell heavily against them.

17. Let us now, to fix our ideas, suppose that we are to design a dynamo for constant pressure. In the first place, we know (sec. 4) that the terminal pressure for a generator is less, and for a motor is greater, than the generated EMF by a product Cr; so that if Cr is small, as it must be for economy, the same machine generates nearly the same EMF as a generator or as a motor with terminal pressures the same, and, therefore, as other conditions are unaffected, the speed must be nearly the same also, so that a generator and a motor to be used in the same circuit may be considered very nearly as the same machine.

18. As the EMF of a dynamo is generated in the armature, and the whole current used must flow through it (excepting for the shunt field of a motor), both factors of the power affect it directly; and as

the field provided by the magnetic circuit is only for the use of the armature, and must, therefore, be designed to suit it, the consideration of the armature is evidently the first and most important part of the design of a dynamo ; so that, after deciding the number of poles to be used, we should proceed to determine what is required of the armature, and select the type.

We know approximately the EMF that it must generate (sec. 4—$E = E_1 + Cr$, of which we know E_1 and Cr is small, and need not be considered at this stage), and the maximum current that must flow through it, allowing a percentage for the shunt circuit (sec. 14). The total armature current is divided between two parallel paths in bipolar dynamos, and between two, four, or more parallel paths in multipolar ones, so that the total current that the armature conductor has to carry is fixed, and from this, knowing the safe carrying capacities of conductors, we can fix the cross section necessary. From 400 to 800 circular mils per ampere for copper gives the common range of practice, the lower values when the machine is run intermittently, or when there is good ventilation, and the higher values for continuous running, or when the ventilation is poor.

19. We may now consider the application of the equation

$$E = 10^{-8}\, c\, v\, l\, \mathfrak{B}$$

The armature of a dynamo consists of the arrangement of a number of conductors (usually copper wire) on a core which is a good magnetic conductor, which is attached to a shaft, and revolves in a magnetic field, so that the conductors cut through the lines of that field as they pass from the poles of the dynamo across the gap—composed of clearance and space occupied by the conductors and their insulation—to the core. As we shall see later in considering the magnetic circuit, it is very important that the depth of this space between pole face and core should be as small as possible.

20. The cross section of the magnetic field is approximately the same as the pole face, and the distribution $\mathfrak{B}$ is fairly uniform in a good design, l is the length of a conductor that is actually cutting through the field $\mathfrak{B}$, and may be taken, therefore, as the length of the pole face, and the length of armature core is usually about the same. The linear velocity of the conductors, *i.e.*, the peripheral velocity of the armature, is v, and c is the number of effective conductors in series, *i.e.*, the number of those in series in which EMF is actually being generated, and which are, therefore, within the polar arcs.

As a means of decreasing the exciting power necessary for a given total magnetic flux (sec. 11) the intensity of magnetization, $\mathfrak{B}$, of the gap spaces is taken quite low, especially for smaller machines, as compared with the limits of saturation of the poles and armature core. The value in practice increases with the capacity of the machine, and is about 50 per cent. higher for wrought iron or steel than for cast-iron pole pieces. For bipolar machines, with cast-iron pole pieces, $\mathfrak{B}$ ranges from 2,300 for 1 kwt. capacity to 4,700 for 300 kwt., or from 15,000 to 30,000 per square inch.

The velocity v as an easily-produced factor of the EMF should be as high as possible. It is limited, however, by mechanical and electrical considerations, such as strain in the moving parts, vibration due to irregularities of balance, friction in the bearings and air friction in the clearance space; eddy currents also and hysteresis losses increase with the speed.* The hysteresis losses depend on the number of reversals per second and the intensity of magnetization of the core. In practice, the peripheral velocities of drum armatures range from 25 to 50 feet per second, increasing with the capacities; and those for ring armatures—on account of their better ventilation and the better hold of the conductors—reach double that amount.

21. We must now select values for $\mathfrak{B}$ and v. We then have c and l to determine, having the relation $cl = \frac{10^8 E}{v\mathfrak{B}}$ between them.

As a question of internal resistance, c and l may nearly balance each other, and it becomes a question then as to whether altering l increases or decreases the idle wire necessary in the particular winding used. But there are other conditions which limit the fixing of c, a consideration of which will help us in making the adjustment. c is the number of conductors in series—in one of the two or more parallel armature circuits—which are actually cutting the magnetic field at a given instant, at any of its two or more pole faces; its ratio to the total number of conductors on the cutting surface is approximately that of the polar arcs to the periphery of the armature space. The length of the polar arc, we find in practice, ranges between 50 and 100 per cent. of the total circumference, and usually lies between 70 and 80 per cent.; questions of magnetic leakage, sparking, etc., affect its length. Fixing this ratio now also fixes the relation between c (the effective) and the total number of *active* armature conductors.

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* *Electrical World*, xxiii., p. 867.

Again, the number of conductors around the circumference, and the number of layers, with a knowledge of the space required for insulation* (between conductors and core, between layers, between sections, and between individual conductors) and that needed for driving horns, will fix the circumference required for the armature and the depth of winding.

The radiating power of the armature fixes the limit of depth of conductors. The greatest current density allowed in practice, that is, the ampere turns per inch circumference, is fixed at about 800, or about 2,500 per inch diameter. The average would be about 600, or 1,900 per inch diameter, which corresponds to a rise of about 70° or 80° centigrade. The depth of winding varies, in practice, with the diameter of the armature, ranging with drum armatures from .25 to .8 inch for diameters of from 2 to 30 inches.

Another question affecting c is the number of sections that there are to be in the armature and in the commutator. Many sections increase the difficulty of winding and insulating, and increase the size and cost of construction of the commutator, while few sections give greater losses in the coils short-circuited under the brushes, causing sparking, and give greater variations in the total EMF generated. Thirty-six divisions cause only a variation of one-fifth of one per cent., so that this would be plenty for steadiness; but, besides this, the self-induction in the short-circuited coils require that the number of loops per section should be kept down, which would both tend to decrease the total number of conductors and to increase the number of sections. From 40 to 60 sections is good practice for pressures up to 300 volts on bipolar machines.

For high pressures, the effect of self-induction in the coils comes still more into play in increasing the number of sections, as also the necessity of keeping the pressure between adjacent segments low enough not to maintain an arc across the insulation between them.†

Let us, then, decide upon a number of sections for the commutator. Each commutator bar will begin one coil and end another, so that the number of armature and commutator sections will be the same.

22. We may now select a value for l, obtained from a similar type of machine in practice, and obtain c and the total number of conductors; then select the nearest number to this which will give the chosen number of sections, and correct the assumed value of l. Knowing now the number of conductors per section, we can decide, from considerations above

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**Electrical World*, xxiii., p. 741.

†*Electrical World*, xxiv., p. 129.

given, and from convenience in winding and insulating, the form that the sections will take and how they will be placed and wound. The circumference of the armature is readily deduced from this, and, therefore, the diameter. We may now see if the length chosen and the diameter deduced bear reasonable proportions to each other; if not, a new value of l may be selected.

23. The selection of the type of armature need not be finally made until after a preliminary calculation of the dimensions, though, as we have seen, a higher value of v is allowed for ring than for drum armatures, which should be considered.

24. We now come to the consideration of the magnetic circuit which produces the fields for the armature conductors to cut. There are a great many different forms of magnetic circuits, and dynamos are classified by the forms and arrangements of these (sec. 15), and, since they can only be utilized for dynamos by conductors cutting through gaps in them, the rest of the circuit is, therefore, only of use as it provides the fields. Electric current circulating in a continuous direction, in coils which surround the material of the magnetic circuit, is necessary to produce and maintain the magnetic flux. *Energy is not necessary to maintain a field.* What is used in the exciting circuit is a more or less necessary waste, for it is all transformed into heat. The excitation is proportional to the product of two terms, the current and the number of times it encircles the flux or NC, and, since only the current involves energy, we have the power to reduce the energy waste by increasing N.

25. As they are interrelated, we may consider together the questions: How do we adjust the proportions of the magnetic circuit? what excitation will be needed for it? and how shall this be provided?

They are, in fact, the discussion of the equation (sec. 11)

$$NC = \frac{10}{4\pi} \Phi \ \Sigma \frac{l}{S\mu}$$

In this equation we have to fix the quantities Φ, and for each part of the circuit the term $\frac{l}{S\mu}$. To fix Φ we have already the intensity of the field $\mathfrak{B}$, its width, which is taken as the length of the pole face, and its depth is calculated from the ratio of polar arc and the circumference of the armature; so that we have the area of the pole face, which is taken as the cross section of the field S, and therefore $\Phi = S\mathfrak{B}$ is determined.

26. We shall now consider the terms $\frac{l}{S\mu}$ for (1) the air gaps, (2) the armature core, (3) the pole pieces, (4) the magnet limbs, and (5) the yoke or connecting pieces.

For the air gaps, we have already settled S; μ is unity, and l is the distance between armature core and pole face, which is made up of depth of winding and clearance. The depth of winding has already been settled. The clearance varies with the diameter, in practice, between $\frac{1}{32}$ and $\frac{7}{16}$ of an inch. The larger distances are for slotted armatures, being found necessary to prevent sparking; it should be as small as possible, but there should be assured safety, for the surface of the armature, from touching the pole face. The smallness of μ makes this the most important term in the calculation. The main reason for making S large or $\mathfrak{B}$ small is now apparent.

27. Let us now deal with the armature core. In the first place, it has to be well laminated, for the reason that iron is a good electrical conductor, so that if the core were made of solid iron, this, cutting the magnetic lines which pass through it, would have the same effect as though conductors on the surfaces were short-circuited, which would waste power if it did nothing worse. The current that would flow in it would be in the same direction as in the conductors; the lamination, therefore, is to effect discontinuity in this direction. If the lamination is too thick, there will still be formed circuits in it sufficient to cause serious loss, and the range of practice seems to be between 10 and 80 mils in thickness. Special insulation is not required between the plates; the coating of oxide formed by heating the iron is sufficient.

The radial depth of the core is fixed so that, after allowing for air space in the lamination, the total cross section is sufficient to keep the value of $\mathfrak{B}$ in it well within the limits of saturation. In bipolar machines the total flux has two paths to take about the centre. In multipolar machines, for each magnetic circuit, it has but one path in the armature. The value of S for the armature is now fixed, since we know the length and have corrected it for lamination already. We must determine μ from tables giving the relation between $\mathfrak{B}$ and μ for the intensity of flux decided on. The average length of magnetic path through the armature core is l, and may be estimated. The hysteresis losses in the core are proportional to the number of magnetic reversals and to the 1.6th power of the intensity of magnetization; for this reason $\mathfrak{B}$ should be lower as the speed increases, to keep down the heat and the heat losses.

28. The quantities l, S, and μ are readily estimated for the pole pieces—the pole face has already been fixed. The general design of the pole should be such as to prevent the unequal distribution of the field. They are often made of cast iron, especially in smaller sizes, when the intensity of the magnetic flux carried by them is not great, and therefore the permeability is large.

29. The magnetic limbs, on the other hand, should be of the best annealed wrought iron, for the cross section, as it affects the cost of winding, as well as the weight of metal, should be a minimum. It should also be circular, as this has the least circumference for a given area. The limbs are usually run pretty well up to saturation, so that $\mathfrak{B}$, and therefore $S = \frac{\Phi}{\mathfrak{B}}$, can now be fixed. For the present, the value of l will have to be estimated, which may be done by comparing similar machines, and it is decided later, when we find the space required for winding. μ is fixed by $\mathfrak{B}$. If the dynamo is to have field regulation for EMF or speed over any considerable range, then the value of $\mathfrak{B}$ chosen should correspond with the field needed for maximum pressure or minimum speed, so as to keep the field below saturation.

30. The cross section of the yoke or other connecting pieces between the limbs should, at least, be as great as the latter, if of the same kind of iron. It is better to have it somewhat larger, so as to bring $\mathfrak{B}$ and μ down. If of cast iron, the value of S, being decided by $S = \frac{\Phi}{\mathfrak{B}}$, would be considerably larger, as the permissible value of $\mathfrak{B}$ would be much smaller. l is again the length of the average path of the magnetic lines (not the length of the yoke over all).

31. We now have all the data for calculating the ampere turns NC necessary to produce the field for the armature conductors to cut. We should find, however, that if we took this value and designed the fields according to the cross sections, etc., above obtained, and provided windings and current accordingly, that the useful flux that we should actually obtain would perhaps be only $\frac{3}{4}$ or $\frac{2}{3}$, or, perhaps, even less, of the amount calculated upon.

The explanation is this: air is a magnetic conductor—not a good one, but still it has conductance, and magnetic lines, instead of passing around, and keeping within the bounds of the circuit, run out from the exciting coils, in more or less wide paths through the air, constituting magnetic leakage. The part of the total flux that does not go through the armature is considerable.

32. If we were to take a practical example of the magnetic circuit, and calculate the ampere turns, or the magnetomotive force necessary for each part of it, we should see that by far the greatest term would be that for the air gaps; so that if we consider the magnetomotive force about the magnetic circuit in the same way that we do EMF about the electric circuit, we see that the drop is proportional to the resistances. The air gap is to the magnetic circuit in a good deal the same relation that the space between plates suspended in acidulated water is to an electric circuit. The reluctance of the air gap is greater than that of the rest of the circuit, and, therefore, the greatest drop of magnetomotive force takes place over it. Wherever we have difference of magnetic potential in a magnetic conductor, we shall find magnetic lines. The pole pieces have great difference of magnetic potential. There are, we may say, two magnetic conductors between them, the air gaps and armature core as one, and the remaining possible paths as the other. Most of the lines will follow the former path, but only in proportion to its magnetic conductivity as compared with the other. In the same way there will be leakage between the limbs, and between the pole pieces and the yoke; although very little between the ends of the yoke. In all cases given the machine the magnetic conductivity of the air spaces is perfectly definite and can be ascertained, and, therefore, the proportion of the lines in a given case that leak though the air and those which are used in the armature can be ascertained.

33. As all the lines (or nearly all of them) will have to pass through the iron within the exciting coils, and through the yoke, we shall have to increase the cross sections of these as calculated, if we wish to keep the value of $\mathfrak{B}$ and μ the same—adding sufficient to them to take the leakage of the rest of the circuit at the same densities $\mathfrak{B}$, thereby retaining the flux ϕ for the armature.

Doing this will be seen not to affect the value of NC calculated; the increased flux is simply proportional to the increased conductance. The ratio of the total to the useful flux is called the co-efficient of leakage, and ranges from 1.1 in large machines of good design to 2 for very small ones.

The determination of the conductances of the air circuits is rather troublesome, so that if it is not necessary to have very accurate results at first a value for the co-efficient of leakage may be assumed by comparing those of similar types of machines; and an allowance may be made for increasing or decreasing the excitations when the machine is tested.

34. There are two more items to be considered in providing ampere turns, which, in bad construction or in bad design, may become of considerable importance: they are the effect of joints and the demagnetizing action of the armature. The former becomes of importance when there are too many joints in the circuit, or when their surfaces are not perfectly even and smooth. The latter is due to a certain number of turns in the armature between the pole horns, which actually surround the magnetic circuit, and have a current in the opposite direction to that of the magnet. It is due to the lead given the brushes to prevent sparking. The effect, evidently, varies with the armature current, *i.e.*, with the load, and can be allowed for, for some particular load, or may be counteracted by compounding.

35. If the field and speed can be kept constant in a generator, then the EMF generated will be constant; but the terminal EMF will drop as the load increases, as we see from the relation $E_1 = E - Cr$ (sec. 4). Now, as it is the terminal pressure that must be kept constant, since the speed cannot be very well increased with the load, the machine is compounded; that is, a winding is provided on the magnet which, by taking the armature current (or that, less the shunt field current), is designed to produce an additional flux, which will increase the EMF generated by the amount Cr over as wide a range of load as possible.

A motor is compounded to maintain constant speed when run on a constant pressure circuit. The series winding acts against the shunt, decreasing the counter EMF by the part Cr in the relation $E_1 = E + Cr$ (sec. 4) as the load increases. As the action of the armature turns, due to negative lead in the motor, is opposed to that of the field turns, just as it is in the generator, it may be made use of in the design of the motor to maintain constant speed, instead of providing a special series winding.

36. We may now decide the relations betweed the turns and current in the fields. We have for the shunt field

$$NC = k_1$$

where k_1 is the calculated value, we have also the relations

$$C = \frac{E}{R} \qquad \text{and}$$

$$R = k_2 \frac{L}{s}$$

where L is the total length, and s the cross section of the wire used, and k_2 is the resistance of unit length of copper conductor of unit cross section. If L is in feet and s in circular mils, then k_2 is the resistance of one foot of wire of one mil diameter = 10.381 ohms at 75° F. Again,

$$L = k_3 N$$

where k_3 is the average length of a turn. Now, if k_3 can be considered nearly constant for a fairly wide range of turns of a given wire, then knowing the excitation required must fix the gauge of wire to be used, for we derive from the above equations the relation

$$s = \frac{k_1 k_2 k_3}{E}$$

k_3 being estimated at first from the diameter of the spools on which the wire is to be wound, and is corrected by trial, as the space to be occupied by the windings is determined.

37. We may now select a value for the current to be used, which must be within the safe carrying capacity of the gauge of wire determined; and calculate the number of turns. The adjustment should be made by balancing running loss against cost of construction. As the field losses are rather a matter of absolute than of relative cost, we find that much larger percentages of the total output are used in field circuits in small than in large machines. They range from about 15 to .015 per cent.

38. In adjusting the excitation due to the series field of the compound winding, the principal necessity is the knowledge of the properties of the magnetic circuit above the degree of its magnetization by the shunt coils, if for a generator, or below, if for a motor, because if lines are added to those already in the circuit, or are taken away, it affects the values of $\mathfrak{B}$ and μ throughout, so that the ratio of the increase of $\mathfrak{B}$ per increase of the magnetizing force must be known.

SOLUTIONS

A. W. Connor, B.A., '95.

Within the last few years much has been written on the subject of solutions, and a great deal of work has been done, rendering what until recently was one of the most obscure branches of physics one of the clearest and best understood; and as in connection with this recent development many interesting problems relating to the voltaic cell have been solved, I propose in this paper to give an account of so much of the new theory of solutions as will be necessary for the proper understanding of its application to these cases.

A solution, in the modern sense of the word, may be defined to be a "gaseous, liquid, or solid mixture, perfectly homogeneous in all its parts"; this extended significance of the word including air, alcohol-water mixtures, and the various solid glasses, as well as those solutions of solids in liquids to which the term was originally restricted.

Liquid solutions, to a consideration of which this paper will be restricted, may be subdivided into:

(1) Solutions of gases in liquids, *e.g*, of ammonia in water.

(2) Solutions of liquids in liquids, *e.g.*, of sulphuric acid in water.

(3) Solutions of solids in liquids, *e.g.*, of salt in water, or resin in alcohol; but that this classification is merely one of convenience may be gathered from the fact that the physical state of the components of the solution varies with the temperature and pressure. Acetic acid, for instance, melts at 16.7° C.; above that temperature a one per cent. solution of the acid in water would come under head (2), below 16.7° C. under (3), although no change in the physical or chemical properties of the solution at that temperature gives indication of any real difference between the two subdivisions.

Another basis of subdivision has been sought in the circumstance that whereas some substances have the power of mixing in all proportions (*e.g.*, alcohol and water), others (*e.g.*, ether and water, carbolic acid and water, camphor and alcohol) can do so only to a limited extent, and still others are known which seem incapable of dissolving in each other at all — such, for instance, is the case with silver chloride and water, water and carbon disulphide, etc. These distinctions, however, like the former, have proved more apparent than real, the difference between the various classes turning out on investigation to be merely one of degree, not of kind : above 70° C., for instance, carbolic acid and water will mix in all proportions, below that temperature they will not*; while careful researches have shown that there is no such thing as a totally insoluble salt, and the solubilities† of silver chloride and barium sulphate in water, though very small, have been experimentally determined.

OSMOTIC PRESSURE.

The distinctive conception of the new theory of solutions is that of "osmotic pressure," developed by Prof. van t' Hoff‡ from data contained in a paper on the physiology of plants, published in 1877 by Dr. W. Pfeffer,§ now Professor of Botany in Leipzig.

He found that a porous clay cell on which a film of cupric ferrocyanide was precipitated was pervious to water, but not to sugar ; that if aqueous sugar solution were enclosed in such a cell and subjected to pressure above a certain amount (depending on the concentration of the solution) pure water would filter through the pores of the cell ; that, on the other hand, if the pressure were kept below this value and the cell were immersed in a vessel of water, the water would enter the cell from without. Other membranes have been discovered possessing similar properties, and solutions of various substances have been experimented on by their aid. The pressure at which equilibrium takes place has been named the "osmotic pressure" of the substance in solution, and has been found :

***Ostwald.* Lehrbuch der Allgemeinen, Chemie, I., 640, 1891.

†A solution is said to be saturated with reference to a certain substance at a given temperature if the solution can remain in contact with that substance without altering in composition, and the number of grammes of the substance dissolved in 100 grammes of the solvent under those circumstances is said to represent the solubility of the substance at the temperature specified.

‡*van t' Hoff.* Une proprieté generale de la matière diluèe, Sv. Vet. Ak.'s Handlingar, xxi., Nov. 17, 1886 ; *also* Die Rolle des Osmotischen Druckes in der Analogie Zwischen Lösungen und Gasen, *Z. Ph. Ch.* (Zeitschrift für Physikalische Chemie), I., 481, 1887.

§*Pfeffer.* Osmotische Untersuchungen, Leipzig, 1877.

(1) Proportional to the concentration of the solution.

(2) Proportional to the absolute temperature.

(3) Equal for solutions of various substances, containing the same number of gramme molecular weights per litre.

(4) To have the same absolute value as the pressure which the same quantity of the dissolved substance would exert in the form of a gas enclosed in the same volume and at the same temperature.

In other words, this "osmotic" pressure varies according to

(1) The law of Boyle.

(2) The law of Charles.

(3) Avogadro's hypothesis; and

(4) In the equation

$$PV = nRT \qquad (1)$$

which is the algebraical expression of these three; the constant R has the same numerical value when P represents the osmotic pressure, T the absolute temperature, n the number of gramme molecules of the dissolved substance, and V the volume of the solution, as when these letters represent the (hydrostatic) pressure, temperature, number of gramme molecules, and volume of a gas.

The importance of these relations will readily be seen; Pfeffer's work furnishes a means of isothermally and reversibly separating solvent from solution, and the quantity of work involved may be calculated from the osmotic pressure by means of the ordinary gas laws.

OSMOTIC PRESSURE AND VAPOR TENSION.

Direct measurements of the osmotic pressure offer exceptional experimental difficulties; the relation, however, which subsists between (*a*) the alteration produced in the vapor tension of a liquid by dissolving another substance in it, and (*b*) the osmotic pressure of that substance in the solution so formed, offers us a ready means of indirectly determining this latter quantity. It has long been known that the boiling point of aqueous solutions of non-volatile substances, *e.g.*, salt, sugar, etc., is higher than that of pure water (or, in other words, that for the same temperature their vapor tension is lower); the quantitative theory of the phenomenon, however, is of comparatively recent date.

It follows directly from the second law of Thermodynamics that if a "reversible circular process" be carried on at constant temperature (isothermally), the quantity of work gained by the system must be equal to that lost (or done). Such a circular process is the following:

Suppose a solution consisting of solvent and dissolved substance in the proportion of N gramme molecules of the former to n of the latter, where n is small in comparison with N.

(1) From a quantity of this solution so large that its composition may be considered as remaining unchanged during the operation remove N gramme molecules of the solvent as follows:

Let A (Fig. 1) be an enclosed vessel containing the solution, and furnished with a cylinder, B, in which the piston, C, permeable for the solvent, impermeable for the dissolved substance, moves without friction. On forcing the piston in the direction of the arrow, water will be removed from the solution and a quantity of work will be done $=PV$, where P is the (constant) osmotic pressure of the substance in solution and V the volume of the N gramme molecules of solvent removed. The value of this quantity may be obtained from the equation

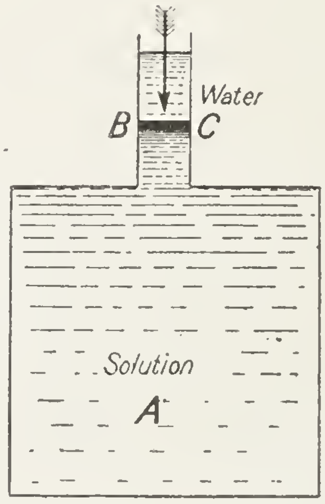

Fig. 1.

$$PV = nRT \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

(the mathematical expression of Boyle's, Gay Lussac's, and Avogadro's laws), in which R is a constant, P is the osmotic pressure, T the absolute temperature, and V the volume occupied by n gramme molecules of dissolved substance (very nearly equal to the N gramme molecules of solvent, the solution being dilute). The work done, then, in this first operation is

$$nRT$$

(2) The N gramme molecules of pure solvent so obtained may now be converted into vapor at the (constant) pressure p (the vapor tension

of the pure solvent at the temperature T), whereby a quantity of work Npv will be gained, where v is the difference in volume between one gramme molecule of the solvent in the form of vapor (at p, and T) and in the form of liquid; or, approximately, the volume in the form of vapor. Making this approximation, and assuming the applicability of the gas laws in their simplest form, viz., $pv = RT \dots\dots\dots\dots (1a)$, the quantity of work gained in the second operation will be

$$NRT$$

(3) These N gramme molecules of vapor are now allowed to expand from the pressure p to the pressure p_1 (vapor tension of the solution at temperature T), the quantity of work gained being

$$N\int_{p}^{p_1} p\,dv = NRT\ \log.\frac{p}{p_1} \dots\dots\dots\dots (2)$$

or, approximately (since $p - p^1$ is small compared with p),

$$NRT\,\frac{p - p_1}{p} \dots\dots\dots\dots (2a)$$

(4) Lastly, the N gramme molecules of the vapor of the solvent are compressed into the solution whereby the pressure keeps constant $= p_1$, and the quantity of work done is (see operation 2)

$$NRT$$

The circular process has now been completed, each one of its four parts is reversible, and has been carried on at the constant temperature T; therefore, the sum of the four quantities of work involved, each taken with its proper sign (work done positive, work gained negative), is

$$nRT - NRT - NRT\frac{p - p_1}{p} + NRT = 0 \dots\dots\dots\dots (3)$$

Whence

$$\frac{p - p_1}{p} = \frac{n}{N} \dots\dots\dots\dots (4)$$

or, "The relative diminution of the vapor tension of the solvent is equal to the ratio of the number of gramme molecules of dissolved substance to the number of gramme molecules of the solvent." And also

$$P = \frac{RT}{V}\cdot\frac{N}{n}\cdot\frac{p - p_1}{p} \dots\dots\dots\dots (5)$$

an equation which connects the osmotic pressure with the temperature, the composition and density of the solution, and the vapor tensions of the solution and the solvent.

OSMOTIC PRESSURE AND FREEZING AND BOILING POINTS OF SOLUTIONS.

The very close connection that exists between the vapor tension of a solution and its freezing and boiling points (a relation by means of which we may with ease experimentally determine the ratio $\frac{n}{N}$) may readily be seen from the following considerations:

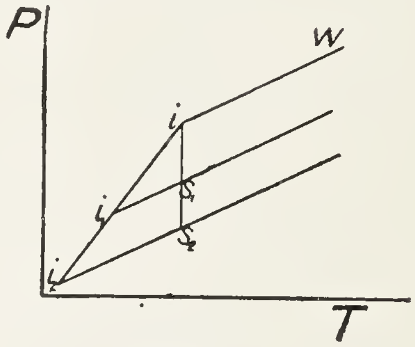

Fig. 2.

In the accompanying figure (Fig. 2), let the line *wi* represent the vapor tension curve for water (*i e.*, a line the ordinates of whose various points represent the pressures of steam in equilibrium with water of the temperatures given by the corresponding abscissæ); let the line $i\,i_1\,i_2$ be the vapor tension curve for ice, and the lines $s_1\,i_1$ and $s_2\,i_2$ the same for the two different salt solutions S_1 and S_2.*

The points i, i_1, and i_2 will then represent the freezing points of water and of the two solutions respectively.

The difference $p - p^1$ between the ordinate of the two lines *wi* and $s_1\,i_1$ at any given temperature is, according to the equation,

$$\frac{p - p_1}{p} = \frac{n}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

equal to $\frac{n}{N}p$, in which $\frac{n}{N}$ (which gives the composition of the solutions,) is constant for the line $s_1\,i_1$, and p may be treated as a constant for small variations of temperature. In other words, within the small limits

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*As the variations of temperature and pressure hereinafter to be considered are very small, the parts of the various vapor tension curves represented in the figure will be treated as *straight lines*.

represented in the figure, $s_1 i_1$ (and similarly $s_2 i_2$) may be considered as *parallel* to *wi*. Now, the distances is_1 and is_2 are proportional to the ratios $\frac{n_1}{N}$ and $\frac{n_2}{N}$; and, on the other hand, the lengths of these same lines, is_1 and is_2, are obviously proportional to the horizontal distances of the points i_1 and i_2 from the line $is_1 s_2$, that is, to the differences between the freezing temperatures of water and of the solutions s_1 and s_2 respectively.

From this it follows that the lowering of the freezing point of the solvent is proportional to the ratio :

$$\frac{\text{No. grm. mols. subst. dissolved}}{\text{No. grm. mols. solvent}}$$

or

$$-dT = k\frac{n}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

k being a constant whose value evidently depends on the angle which the lines *wi*, etc., make with the T axis; its numerical value has been found from thermodynamical considerations* to be $\frac{Q}{2T^2}$, where Q is the latent heat of fusion of solvent and T the absolute temperature. Introducing this value into (5) it becomes

$$-dT = \frac{Q}{2T^2} \times \frac{n}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5a)$$

A perfectly similar line of argument leads to an analogous expression for the raising of the boiling point.

MOLECULAR WEIGHTS OF DISSOLVED SUBSTANCES.

The relations obtained in the last two pages connecting the ratio $\frac{n}{N}$ with :

(*a*) The osmotic pressure of the dissolved substance,
(*b*) The diminution of the vapor tension } of the solvent,
(*c*) The lowering of the freezing point } of the solvent,
(*d*) The raising of the boiling point } of the solvent,

have been made use of in determining the molecular weights of dissolved substances, for a knowledge of the molecular weight of the solvent (in the state of gas) and of the composition of the solution gives N, a determination of any one of the quantities (*a*), (*b*), (*c*), (*d*) above gives $\frac{n}{N}$, and the product of the two is n, or the number of gramme molecules contained in the (known) weight of the dissolved substance, hence the molecular weight of the latter.

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*van t' Hoff, loc. cit., p. 496.

The molecular weights obtained in this manner have in many cases proved identical with those expected from purely chemical grounds, sometimes, however, notably in the case of solutions of salts, strong acids, and strong bases, the number of molecules, as deduced from freezing point depression, etc., has been found to be two, three, or more times as great as can be accounted for if the molecular constitution represented by its chemical formula be assigned to the dissolved substance.

A similar discrepancy had years before been noticed in the molecular weights of certain gases. A density determination showed that the number of molecules contained in the vapor evolved on heating a given quantity of ammonium chloride was twice that calculated by the help of Avogadro's hypothesis* from the chemical formula NH_4Cl; the explanation suggested, viz., that the substance had undergone chemical decomposition ("dissociation") into ammonia and hydrochloric acid gas, although at first scouted as "contravening all the laws of chemical affinity," has since been confirmed by direct experimental evidence. The attempt, however, to account for the "abnormal depression of the freezing point" of water by salts, strong acids, etc., in a similar manner was balked by the difficulty of saying into what such a substance as sodium chloride (NaCl), for instance, *could* possibly be "dissociated."

ELECTROLYTIC SOLUTIONS.

The fact that these "abnormal" results were obtained chiefly with solutions of electrolyte, however, has led to a hypothesis which, originally put forward to explain a limited number of phenomena, has proved itself an invaluable assistance in all investigations into the nature of electrolytic solutions.

That aqueous salt solutions can conduct electricity was well known to Galvani and Volta; that chemical decomposition accompanies the passage of the current through them seems first to have been discovered by Nicholson and Carlisle (1800); but a quantitative investigation of the products of this decomposition was first undertaken by Faraday, who established the first and second of the following four general statements:

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* "Equal volumes of all gases at the same temperature and pressure contain the same number of molecules," or, as the atomic weight of hydrogen has been adopted as the unit, and the molecule of hydrogen contains two atoms, 22.327 litres at 0°C and 760 mm. (which would contain two grammes of hydrogen) will contain the molecular weight in grammes of any gas.

(1) The quantity of salt decomposed in a given time is proportional to the current.

(2) If the same current be passed through solutions of various salts, chemically equivalent quantities of these salts are decomposed. (Faraday's law.)

Apart from this decomposition, however, there has often been observed:

(3) An alteration of the concentration of the undecomposed electrolyte along the line of flow of the current. Thus, for instance, if electricity be passed through copper chloride solution between platinum electrodes copper will be deposited at the kathode,* and chlorine set free at the anode; but, besides this, at the end of the experiment, that half of the solution towards the anode will be found to contain more copper chloride than the half in the neighborhood of the kathode. The quantitative investigation of this phenomenon is due to W. Hittorff.†

(4) In all other respects, however, the conduction of electricity by electrolytes resembles that by metals, and is subject to the laws of Ohm and of Joule.

ION THEORY.

Faraday represented the passage of electricity through the solution as effected by the actual motion of translation of material particles (which he identified with the then recently invented "atoms" of Dalton), each one carrying an equal (positive or negative) charge, much as the pith balls in the familiar electrostatic experiments. Such of these particles as were positively charged would tend to move towards the (negatively charged) kathode, and were hence named "kations," the others (moving in the opposite direction) "anions." The electrical neutrality of the solution he explained by assuming the existence of equal numbers of these two classes of ions.

Thus in the electrolysis of a solution of sodium chloride, he imagined the sodium atoms, each with its appropriate charge of positive electricity,

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*The *anode* is that pole which is metallically connected to the positive pole o the source of E.M.F., the *kathode* to the other. According to the usual convention, the + current is supposed to enter the *electrolyte* (*i.e.*, the conducting solution) by the anode and leave it by the kathode.

†*W. Hittorff.* Wanderung der Ionen waehrend der Elektrolyse Pogg. Ann., LXXXIX., 177; XCVIII., 1; CIII., 1; CVI., 337 and 513; 1853-1859. Reprinted in *Ostwald's* Klassiker, Nos. 21 and 23, Leipzig, 1891.

as moving "down" towards the kathode, while the chlorine atoms were carrying their negative charges "up" to the anode. If the atoms of the various elements be supposed to carry charges proportional to their valency, we can deduce from Faraday's ion theory the second of the above general propositions. The variations in concentration may be accounted for by assuming that under similar circumstances (*e.g.*, the same difference of potential per centimetre) the various ions ($\overset{+}{\mathrm{K}}$, $\overset{++}{\mathrm{Cu}}$, $\overset{-}{\mathrm{Cl}}$, $\overset{--}{\mathrm{SO_4}}$, etc.) move at different rates; for in the electrolysis of copper chloride solution, mentioned above, if the chlorine ions move toward the anode quicker than the copper ions toward the kathode (the condition of electrical neutrality of the solution being maintained), the concentration of the copper chloride will become relatively greater in that part of the solution nearest the anode; and conversely experimental measurements of the alterations in concentration, brought about by the passage of a current, have led to the determination of the relative velocities of the various ions.

The next step in the development of this "ion theory" of electrolysis was taken by Kohlrausch, who found that the "molecular conductivity"* (μ) of *dilute solutions* of salts, and of some acids and bases, was an "additive" property, *i.e.*, might be measured in each case by the sum of two specific constants, one for the kation and one for the anion. In endeavoring to give a physical meaning to these constants, he was led to the conjecture that they might possibly represent the rates at which the various ions transport the electrical charge, and a careful comparison of his own results with those of Hittorff showed this hypothesis to be well founded. The result of his investigation he expressed in the formula

$$\mu_{\infty}=\mathrm{u}+\mathrm{v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

or, "molecular conductivity in extremely dilute solutions is equal to the sum of the velocities expressed in suitable units of the anion and of the kation."

The molecular conductivities of more concentrated solutions he found to be less than those of the dilute.

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*The conductivity (in reciprocal ohms) of such a quantity of the solution as contains a formula weight in grammes of the salt, when enclosed between electrodes one centimetre apart. It will be seen from this definition that the molecular conductivity may be obtained by multiplying the number of cubic centimetres of the solution that contain one gramme formula weight of salt *into* the "specific conductivity" of the solution, *i.e.*, the conductivity of a cube whose side measures one centimetre.

The following table* shows the extent of the agreement between the experimental results and those calculated by means of equation (7): the values are for 18° C. and for extremely dilute solutions.†

TABLE I.

Values of u for K=52. Na=32. Li=24. Ag=42. H=272. $\frac{1}{2}$Zn=24.

Values of v for Cl=54. I=55. NO_3=48. OH=143.

	Molecular Conductivity, μ_∞		Transport of the Anion $\frac{v}{u+v}$.	
	Obs'd.	Calc'd.	Obs'd.	Calc'd.
KCl	105	106	0.51	0.51
NaCl	87	86	0.63	0.63
HCl	324	326	0.19	0.17
$AgNO_3$	89	90	0.53	0.53
$\frac{1}{2}ZnCl_2$	77	78	0.70	0.69
KOH	199	195	0.74	0.73

NOTE.—The "observed" molecular conductivities are from a paper by Kohlrausch; the "observed" transport values are from Hittorff's work.

This theory of ions, though admirably adapted to explain the phenomena of electrolysis, was looked on askance by the great majority of chemists, whose ideas of the true nature of things were inexpressibly shocked by the idea of sodium atoms—with or without a "charge of

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*Ostwald. Lehrbuch II., 646 (in part).

†As the transport values vary markedly with the concentration of the solution, the following table of the relative velocities of the kations of a few common salts in "normal" aqueous solutions (which contain one gramme formula weight of the salt in one litre of the solution) will be of more practical use in the calculation of electromotive forces—as will appear further on:

TABLE 2.

Salt.	Ions.	Relative Velocity of Kation $\frac{u}{u+v}$
Hydrochloric acid	H,Cl	0.82
Sulphuric acid	2HS,O_4	0.82
Potassium chloride	K,Cl	0.48
Potassium sulphate	2K,SO_4	0.5
Magnesium chloride	Mg.2Cl	0.26
Magnesium sulphate	Mg,SO_4	0.25
Zinc sulphate	Zn,SO_4	0.28
Cadmium chloride	Cd,2Cl	0.26
Copper sulphate	Cu,SO_4	0.276
Silver nitrate	Ag,NO_3	0.50

(The values are taken from *Ostwald*, Lehrbuch II.)

electricity"—existing in contact with a substance so violently acted on by metallic sodium as is water. The most they could allow was the existence of a few stray ions here and there, and one can easily imagine the stir caused by a paper of Sv. Arrhenius,* who assumed that in a *dilute* common salt solution *all* of the salt existed in the form of sodium ions $\overset{+}{\text{Na}}$ and chlorine ions $\overset{-}{\text{Cl}}$, and that in more concentrated solutions the fraction of the salt in the state of ions was given by the ratio between the molecular conductivities of the more concentrated and of the dilute solution, *i.e.*, α being the fraction of the salt in the state of ions,

$$\alpha = \frac{\mu_{\text{v}}}{\mu_{\infty}} \quad \ldots\ldots\ldots \quad . \ldots. \quad \ldots (8)$$

where μ_{v} is the molecular conductivity of a solution containing one gramme molecule of salt in the total volume V; and μ_{∞} the limiting value of the molecular conductivity in an extremely dilute solution.

IONS AND OSMOTIC PRESSURE.

This hypothesis of Arrhenius suggested to van t' Hoff, in answer to the question referred to on page 230, that the *dissociation products* of sodium chloride (needed to explain the "abnormalities" in freezing point, etc., of its solution) might be none other than these very *ions* which were introduced in order to account for the phenomena of electrical conduction of the same solution; and the fact, already mentioned, that the class of electrolytes furnished the most striking variations from the simple laws as to vapor pressure diminution, etc., served to render the assumption plausible from the first.

If the molecules in a sodium chloride solution are *not* NaCl, but $\overset{+}{\text{Na}}$ and $\overset{-}{\text{Cl}}$, there are obviously twice as many of them present in a given volume of the solution as was thought, and a depression of the freezing point twice that calculated on the assumption of NaCl molecules is at once accounted for. Speaking generally, if one molecule of the electrolyte (as expressed by its chemical formula) give rise to *m* ions (*e.g.*, NaCl two, CaCl_2 three., viz., $\overset{++}{\text{Ca}}$, $\overset{-}{\text{Cl}}$, $\overset{-}{\text{Cl}}$), and if α be the fraction of the salt

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**Sv. Arrhenius.* Sur la conductibilité galvanique des electrolytes. Bihang till K. Svenska Vet. Akad. Handlingar—Band. 8, No. 13, 1884. *Also,* Ueber die Dissociation der in Wasser gelösten Stoffe, *Z. Ph. Ch.*, I., 631, 1887.

in the state of ions,* then for every formula-weight in grammes of salt in the solution we have $1-\alpha$ gramme molecules of undecomposed salt and α decomposed, yielding $m\alpha$ ions, or, in all, $1-\alpha+m\alpha$, or $1+(m-1)\alpha$ gramme molecules, counting the ions as independent molecules; and the depression of the freezing point will be $1+(m-1)\alpha$ times "too great," while the molecular electrical conductivity will be $\alpha\Sigma(u+v)$ where $\Sigma(u+v)$ represents the sum of the velocity constants of the various ions involved. By means of these relations, electrical conductivity and freezing point (similarly the boiling point, vapor tension, etc.) are connected, and one being experimentally determined the other may be calculated. The remarkable success of calculations of this nature has very materially contributed toward the general acceptance of a theory that furnishes a link between two branches of physics so dissimilar.

IONS AND THE MASS LAW.

The success attending this first venture at treating the ions as full-fledged molecules, natuarally soon led to a second, viz., an application of the law by which, in the case of gases, the dissociation may be expressed in terms of the concentration. The quantitative expression of this relation is contained in the equation of Guldberg and Waage† (the so-called "Mass law").

$$\frac{C_1^{n_1} \cdot C_2^{n_2} \cdot C_3^{n_3} \; . \; . \; .}{C} = \text{Const.} \; \ldots\ldots\ldots (9)$$

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*Value of α for "normal" solutions of various electrolytes at ordinary temperatures:

(1) Salts of the alkalis, of ammonium, and of silver, with monobasic acids, about 0.75 to 0.8.

(2) Zinc sulphate, copper sulphate, etc., dissociating into two ions with double charge, about 0.25.

(3) Monobasic acids and monacid bases; all values from about 0.8 for "strong" acids and bases, *e.g.*, HCl and KOH down to about 0.01 for acetic acid and ammonia, and even less for many of the weaker organic acids and bases.

†This important equation, whose relation to the fundamental principles of thermodynamics has been clearly shown by Prof. W. Gibbs (Transactions Connecticut Academy, III., 231, 1876), was first deduced by Guldberg and Waage, 1867, from considerations as to the velocity of chemical reactions. Wilhelmy had shown as early as 1850 that in many cases the quantity of chemical change taking place in a given time is proportional to the concentration of the reacting bodies, or that the "velocity"

$$v = KC_1C_2 \; . \; . \; .$$

In case the reaction be "reversible," *i.e.*, if the products of the chemical action of two (or more) substances can recombine to form the originals, as, for example, in the case

C being the concentration (gramme molecules per litre) of the undecomposed substance; C_1, C_2, etc., the concentrations of the various products of dissociation; and n_1, n_2, etc., the number of molecules of each of these latter formed from one molecule of the original substance. For example, in the case of phosphorus pentachloride, which on heating decomposes as follows:

$$PCl_5 = PCl_3 + Cl_2 \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

one molecule of phosphorus trichloride and one of chlorine being formed from one of phosphorus pentachloride, the Guldberg and Waage's equation takes the form:

$$\frac{\text{Concentration } (PCl_3) \times \text{Concentration } (Cl_2)}{\text{Concentration } (PCl_5)} = \text{Const.} \ldots (11)$$

If the "dissociation" of sodium chloride in solution into sodium ions and chlorine ions

$$NaCl = \overset{+}{Na} + \overset{-}{Cl} \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

be subject to the same law, the following relation must hold good:

$$\frac{\text{Concentration } (\overset{+}{Na}) \times \text{Concentration } (\overset{-}{Cl})}{\text{Concentration } (NaCl)} = \text{Const.} = K \ldots\ldots (13)$$

or (from the definition of "concentration" given above)

$$\frac{M(\overset{+}{Na}) \times M(\overset{-}{Cl})}{M(NaCl)} = KV \ldots\ldots\ldots\ldots (13a)$$

where $M(\overset{+}{Na})$ denotes the mass of sodium ions expressed in gramme

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Alcohol + Acid Ether + Water,

the change actually observed will be only the difference between the quantity of alcohol and acid which are used up in the reaction, and the quantities that are re-formed by the reaction, and when equilibrium is reached, *i.e.*, when no further change in the relative quantities of the four reagents takes place,

$$0 = v_1 - v_2 = K_1C_1C_2 - K_2C_3C_4$$

$$\text{or } \frac{C_3C_4}{C_1C_2} = \frac{K_1}{K_2} = K$$

Equation (9) above gives the relation in its most general form.

molecular weights, and similarly with $M(\overset{-}{Cl})$, etc.; V is the total volume occupied by the solution, in litres.

In the special case that the solution contains but one salt, the chemical equation of decomposition furnishes a relation between the masses of the various dissociation products. In the example selected, it follows from (12) that $M(\overset{+}{Na})$ and $M(\overset{-}{Cl})$ are equal, and (13*a*) takes the form:

$$\frac{M^2(\overset{-}{Cl})}{M(NaCl)} = \frac{M^2(\overset{+}{Na})}{M(NaCl)} = KV \dots\dots\dots\dots\dots \quad (13b)$$

Representing the fraction of the salt in the state of ions by α (as on p. 234), then the one formula-weight of salt dissolved has given rise to α gramme molecules of (each) $\overset{+}{Na}$ and $\overset{-}{Cl}$ and $1-\alpha$ gramme molecules NaCl; so that (13*b*) may be written

$$\frac{\alpha^2}{1-\alpha} = KV \dots\dots\dots\dots\dots\dots\dots \quad (13c)$$

which, on substituting for α its value from (8), becomes

$$\frac{\mu^2_{v}}{\mu_\infty(\mu_\infty - \mu_v)} = KV \dots\dots\dots\dots\dots\dots \quad (13d)$$

an equation connecting the molecular conductivity of the solution with the concentration of the dissolved substance, which obviously holds not only for the special case here considered, but also wherever one molecule of an electrolytic substance gives rise on dissociation to equal quantities of two ions. This is true for all monobasic acids, *e.g.*, acetic acid

$$CH_3COOH = (\overset{-}{CH_3COO}) + \overset{+}{H}$$

for all monacid bases, *e.g.*, potassium hydrate

$$KOH = \overset{+}{K} + (\overset{-}{OH})$$

and for many salts, *e.g.*, silver nitrate and zinc sulphate

$$AgNO_3 = \overset{+}{Ag} + (\overset{-}{NO_3})$$
$$ZnSO_4 = \overset{++}{Zn} + \overset{--}{SO_4}$$

The accuracy of this relation, and therewith the applicability to the case of dissociation in solution, of a quantitative law originally obtained for the dissociation of gases was immediately tested* by careful comparison with the experimentally determined conductivities of over two hundred organic acids in solutions of varying concentration. The remarkable agreement between the experimental values and those calculated by equation (13*d*) attracted great attention, and contributed largely to create confidence in the new theory of solutions. Since this time, many other applications of the law of Guldberg and Waage to the case of solutions have been made with equal success. Of these but one need be considered here. A reference to equation (9) shows that if the concentration of any one of the dissociation products be increased (by addition from without), the quantity of undissociated substance in the solution will also necessarily increase; thus the dissociation of the acetic acid† in aqueous solution

$$CH_3CO.OH=CH_3\overset{-}{CO}\cdot O+\overset{+}{H}$$

would be diminished by the addition of (*a*) any salt of acetic acid (*i.e.*, the ion $CH_3.\overset{-}{CO}.O$), or (*b*) any "strong" (much dissociated) acid (*i.e.*, $\overset{+}{H}$). Thus, speaking generally, the total number of ions contained in the (separated) solutions of two substances possessing a common ion will be diminished on mixing the solutions, and, hence, the specific conductivity of the mixture will be less than the average of the conductivities of the solutions before mixing. This relation, also, has been reduced to quantitative form, and tested by experiment, with satisfactory results.

ELECTROMOTIVE FORCES.

The most recent triumphs, however, of the new solution theory have been in connection with calculations of the E.M.F. of cells. Previous attempts at such calculations had been made by H. v. Helmholtz§ and by Sir Wm. Thomson‡ who, acting on the assumption that all of the

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***Ostwald.* Zur Theorie der Lösungen, *Z. Ph. Ch.*, II., 36, 1888. Dissociationstheorie der Elektrolyte, *Z. Ph. Ch.*, II., 270, 1888.

†*Sv. Arrhenius.* Gleichgewichtsverhältnisse zwischen Elektrolyten, *Z. Ph. Ch.*, V, 1., 1890.

§*H. v. Helmholtz.* Erhaltung der Kraft, 1847. *Ostwald's* "Klassiker," No. 1, Leipzig, 1889.

‡*W. Thomson.* *Phil. Mag.*, (4) 2, 429, 1851.

energy set free by the chemical action in the cell could be converted into electrical energy, equated the mechanical equivalent of the "heat of reaction" for the chemical change taking place in a given cell to the product of the quantity of electricity transferred during these changes into the E.M.F.

REVERSIBLE CELLS.

The results obtained from calculations based on this assumption were soon found to differ widely from the results of experiment; and simultaneously, the science of thermodynamics, now undergoing rapid development at the hands of Clausius and others, tended to cast grave suspicion on the fundamental hypothesis underlying the calculations themselves. A period of thirty years, however, elapsed before these problems were attacked again from the more modern point of view; this time, again, by v. Helmholtz.*

A large number of galvanic cells are "reversible machines" in the thermodynamical sense; that is, not only will the chemical decomposition produced in the cell be reversed by a change in the direction of the current,‡ but the E.M.F. which must be opposed in order to produce this change in direction need be greater than the E.M.F. of the cell itself by but an infinitesimal amount.

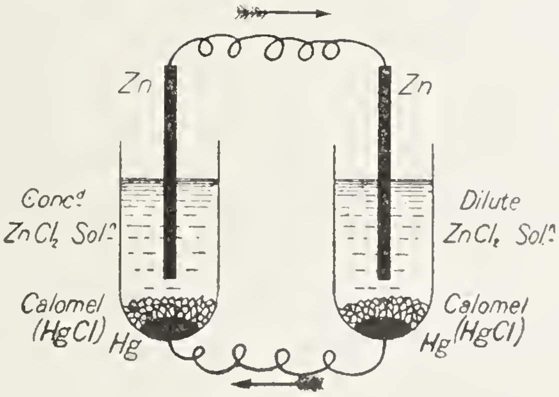

Fig. 3

Such a cell, for instance, is the combination

Amalgamated zinc | Zinc chloride solution | Mercurous chloride | Mercury

two of which are represented in opposition in Fig. 3. When the electrodes of one of the so-called "calomel cells" are metallically con-

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*v. *Helmholtz*. Monatsbericht der k. pr. Akad d. Wiss. zu Berlin, 1877, p. 713.

‡Which, for instance, is approximately true in the case of the storage battery.

nected, the zinc of the zinc electrode dissolves, forming zinc chloride with the chlorine of the calomel, while the mercury of the latter is deposited at the other (mercury) electrode. The E.M.F. at 15° C. of a cell filled with zinc chloride solution of s.g. 1.409 is 1.000 volts, and, if it be opposed by an external E.M.F. of any higher value, the zinc will be precipitated on the zinc electrode and the surface of the mercury electrode will be attacked with the formation of calomel. But although the decompositions produced in the cell by its own action are those expressed by the chemical equation

$$Zn + 2HgCl = ZnCl_2 + 2Hg \quad \ldots\ldots\ldots\ldots\ldots (14)$$

there is, in addition, a change taking place which is not represented there, *viz.*, an increase of concentration in the zinc chloride solution ; and if two "calomel cells" be set up in opposition, as in Fig. 3, and a current pass in the direction of the arrows, this latter change is the only net effect of the operation ; for just as much zinc is precipitated in the left-hand cell (cell No. 1) as is dissolved in the other, and the quantity of calomel decomposed in cell No. 2 is precisely equal to that formed in No. 1, the whole effect of the passage of the current being merely to increase the concentration of the zinc chloride solution* in No. 2 and to decrease it in No. 1.

APPLICATION OF THE SECOND LAW OF THERMODYNAMICS.

An apparatus, then, such as the one under consideration (Fig. 3) furnishes an electrical means of isothermally and reversibly bringing about alterations in the concentration of a zinc chloride solution, and must require the same quantity of work to effect this result as would be required to effect the same result by means of any other isothermal reversible process ; otherwise these two processes could be combined (the first operating in one direction and the second in the reverse) to form an isothermal cycle, yet capable of supplying any desired quantity of work, the only source of which could be the heat of the surroundings ; a proposition directly at variance with the fundamental conceptions of the second main principle of thermodynamics, according to which a difference of temperature is absolutely necessary in order that heat may be converted directly into work.

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*As there is solid calomel present in the cell, the concentration of the mercurous chloride dissolved remains constant.

The application of this theorem to the cases in point is simple and direct. The electrical work that must be done in order to bring about a certain alteration of concentration in the two electrolytes is obviously the integral of the quantity of electricity passed through the cells into the resultant electromotive force of the combination at each instant: if, then, any other reversible method be known, by means of which this same effect can be produced, and if the work necessary in this latter case be known, an expression equating these two quantities of work* furnishes a means of calculating the E.M.F. of the cell combination in question.

In the paper of v. Helmholtz before referred to, he selects as his second means of altering the concentration of the electrolyte the method of directly evaporating the water at a pressure equal to its vapor tension over the solution, and thus by expressing the vapor tension of aqueous zinc chloride solutions of various concentrations in terms of these concentrations, he was enabled to perform the remarkable feat of calculating the E.M.F. of an electrical battery from entirely independent data.

RELATION TO OSMOTIC PRESSURE.

It will readily be seen by those who have carefully read the earlier part of this paper that the vapor tensions in Von Helmholtz's formula for the E.M.F. may be replaced by expressions containing the osmotic pressure of the dissolved substances.† The first attempt, however, to attack this problem from the point of view of the modern theory of solutions was made by Prof. W. Nernst in an important paper published in 1889.‡

Starting, as did v. Helmholtz, from the theorem that the work to be obtained by the passage of a system from one state to another by any isothermal reversible process is independent of the special nature of that process, he equated the work which would be done by the osmotic forces during the passage of the zinc chloride from the stronger to the weaker solution§ to that obtainable by the electrical process which leads to the same result; that is,

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* In conjunction with Faraday's law, connecting current and amount of chemical change produced.

† The vapor tensions of solutions being known functions of the osmotic pressures of the dissolved substances; see page 229.

‡ *W. Nernst.* Elektromotorische Wirksamkeit der Ionen, *Z. Ph. Ch.*, IV., 130, 1889.

§ As in the case of a gas, the work done in bringing one gramme molecule from pressure p_1 to p_2 is $\int_{p_1}^{p_2} pdv$, from which by substituting for p its value from equation (1) the expression in (15) is obtained.

$$4.18 n_i RT \log. \frac{p_1}{p_2} = n_e \varepsilon \pi \ldots\ldots\ldots\ldots\ldots\ldots (15$$

Where

4.18 is the mechanical equivalent of heat (in Joules).

n_i the number of gramme ions contained in the solution of one gramme formula weight of salt.

p_1 and p_2 the osmotic pressures of the zinc chloride in cells (1) and (2) respectively.

n_e the number of electrical equivalents represented by one atom of the dissolved metal (for zinc $n_e = 2$).

ε the quantity of electricity which on passing through a salt solution decomposes one gramme equivalent of the salt, viz.: 96,540 coulombs.

π the E.M.F. of the combination.

T the "absolute" temperature.

R the constant of equation (1)——$RT = 2T$ cal.

Whence

$$\pi = 4.18 \frac{n_i}{n_e} \frac{R}{\varepsilon} T \log. \frac{p_1}{p_2} \text{ volts} \ldots\ldots\ldots\ldots (15a)$$

or collecting the constants and substituting Briggs' logarithms for natural

$$\pi = 0.0002 \frac{n_i}{n_e} T \log._{10} \frac{p_1}{p_2} \text{ volts} \ldots\ldots\ldots\ldots (15b)$$

This quantity π, the electromotive force of the combination represented in Fig. 3, is, evidently, equal to $\pi_1 - \pi_2$, the difference between the E.M.F. of cells (1) and (2). If the concentration of the solution (and, therefore, the E.M.F.) of cell (2) be kept constant, while that of cell (1) is arbitrarily varied, then the E.M.F. of cell (1)

$$\pi_1 = \pi + \pi_2 = 0.0002 \frac{n_i}{n_e} T \log._{10} p_1 + (\pi_2 - K) \text{ volts} \ldots\ldots (15c)$$

(Where K = the constant quantity $0.0002 \frac{n_i}{n_e} T \log._{10} p_2$)

and as the osmotic pressures are, at all events in dilute solutions, proportional to the concentrations, this expression shows the relation between the E.M.F. of a cell and (1) the concentration and (2) the state of dissociation of the electrolyte.

Another example of the facility with which the theory of osmotic pressure lends itself to the solution of problems of this nature was shortly afterwards furnished by V. v. Türin.* In the case of a cell whose electrodes are composed of zinc amalgam of different concentrations (Fig. 4), the electrolyte being the solution of a zinc salt, the electromotive force may be arrived at by setting the electrical work gained during the transference of an elementary mass of zinc from the stronger to the weaker amalgam to that which might be obtained by its passage under the influence of the osmotic forces from its more concentrated to its more dilute solution in mercury; or,

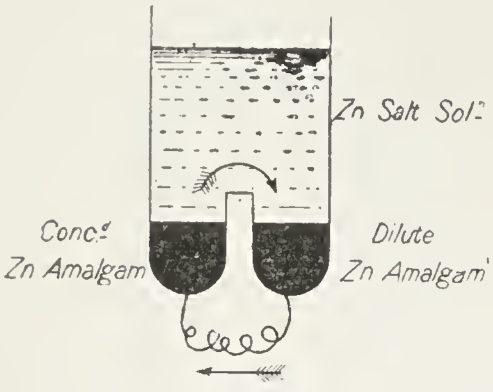

Fig. 4

$$n_e \varepsilon \pi = 4.18 \, n_i RT \log. \frac{p_1}{p_2} \, \dots\dots\dots\dots\dots\dots \, (16)$$

an equation identical in form with (15), but in which p_1 and p_2 represent the osmotic pressures of the zinc in the zinc amalgam electrodes of cells (1) and (2) respectively. Whence, as before,

$$\pi = 0.0002 \frac{n_i}{n_e} \, T \log._{10} \frac{p_1}{p_2} \text{ volts} \dots\dots\dots\dots (16a)$$

in which $\frac{p_1}{p_2}$ may be set equal to $\frac{c_1}{c_2}$, the ratio of the concentrations of the zinc in the two amalgam electrodes; $n_e = 2$; and n_i has been found to be unity by experiments on the freezing point of solutions of zinc in mercury.

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* *V. v. Türin.* Molekulargewichte der Metalle, *Z. Ch. Ph.*, V., 340, 1890. See also *G. Meyer*, Bestimmung des Molekulargewichtes einiger Metalle, *Z. Ph. Ch.*, VII., 477, 1891.

The case of the combination represented in Fig. 5 is of peculiar interest. This, as will be observed, differs from the arrangement in Fig. 3, in that the circuit is completed by direct communication of the electrolytes (through a siphon)* instead of by means of the mercury electrodes and metallic connection of the latter. Under these circumstances, while one equivalent of silver is dissolving at the anode, the quantity

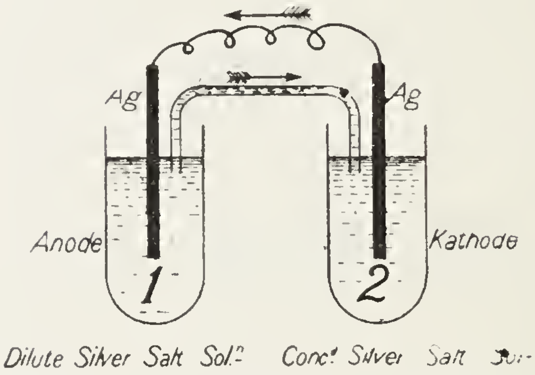

Fig. 5.

$$\frac{u}{u+v}$$

passes through the siphon towards the kathode, and the resulting increase of concentration in cell (1) is only

$$1-\frac{u}{u+v}=\frac{v}{u+v}$$

with which factor the expression (15*b*) must be multiplied, giving

$$\pi=0.0002\,\frac{v}{u+v}\,T\,\log._{10}\frac{c_1}{c_2}\text{ volts}\ldots\ldots\ldots\ldots(17)$$

as the electromotive force of the combination in question.

INDIVIDUAL ELECTROMOTIVE FORCES.

This last example leads directly to a consideration of the cases in which an E.M.F. is produced through the contact of two electrolytes.

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*Simultaneously with the reversible motion of the ions under the influence of the electrical forces, there takes place a non-reversible diffusion through the siphon, tending to equalize the concentration in the two cells. Owing to the comparative slowness of the diffusion, however, the effect produced by it during the small time necessary to make an E.M.F. measurement may be neglected.

While a quantity of positive electricity corresponding to one gramme molecular weight passes through the siphon in the direction of the arrow (Fig. 6), the quantity $\frac{u}{u+v}$ of the kation moves out of cell (1) into cell (2). Suppose the solution in cell (1) to be more concentrated than in cell (2), this transference would yield (in reversible osmotic piston and cylinder apparatus) the work

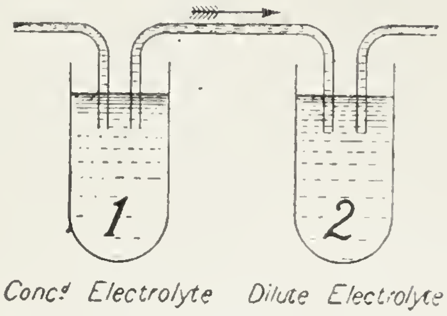

Fig. 6.

$$4.18 \frac{u}{u+v} \, n_i RT \log. \frac{p_1}{p_2}$$

but during the same time the quantity $\frac{v}{u+v}$ of the anion has gone from the (dilute) cell (1) to the (concentrated) cell (2); which second transference could be effected by the osmotic pressure apparatus only by the expenditure of the work

$$4.18 \frac{v}{u+v} \, n_i RT \log. \frac{p_1}{p_2}$$

a gain, on the whole, of

$$4.18 \frac{u-v}{u+v} RT \log. \frac{p_1}{p_2}$$

which, as all processes here considered are isothermal and reversible, may be set equal to the electrical work $n_e \varepsilon \pi$.

From this relation it follows, collecting constants, etc., as before that the E.M.F. in the siphon*

$$\pi = 0.0002 \frac{u-v}{u+v} T \log._{10} \frac{p_1}{p_2} \text{ volts} \ldots\ldots\ldots\ldots (18)$$

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*Silver is selected as the type of a monovalent kation; for divalent, etc., kations (*e.g.*, zinc) the formulæ are somewhat more complicated. The general expression for the E.M.F. at the contact of two solutions of the same salt of different concentrations is

$$\pi = \frac{\frac{u}{n} - \frac{v}{m}}{u+v} \cdot \frac{RT}{\varepsilon} \log. \frac{p_1}{p_2} = \frac{\frac{u}{n} - \frac{v}{m}}{u+v} \, 0.0002 \, T \log._{10} \frac{p_1}{p_2} \ldots\ldots\ldots (18a)$$

where n is the valency of kation, m that of the anion.

an expression of very considerable interest, furnishing, as it does, the first example* of the calculation of an "individual" E.M.F. For it will be seen that π in equations (15*c*), (16*a*), and (17), referring to Figs. 3, 4, and 5, is the algebraic sum of several of such "individuals"; for instance, the E.M.F. of the cell-combination represented in Fig. 3 is the resultant of:

(1) EMF between zinc and electrolyte in cell (1).
(2) " electrolyte and mercury in cell (1).
(3) " mercury and (platinum) wire in cell (1).
(4) " platinum and mercury in cell (2).
(5) " mercury and electrolyte in cell (2).
(6) " electrolyte and zinc in cell (2).
(7) " zinc and wire in cell (2).
(8) " wire and zinc in cell (1).

Professor M. Planck (*Wied. Ann.*, xl., 561, 1890) has deduced a formula for the still more general case, where the two solutions contain a number of different electrolytes which are not necessarily the same in each. The equation runs:

$$\pi = 0.0002\ T \log. x \quad \ldots\ldots\ldots\ldots\ldots\ldots (18b)$$

in which x is defined by the relation

$$\frac{xU_2 - U_1}{V_2 - xV_1} = \frac{\log. \frac{c_2}{c_1} - \log. x}{\log. \frac{c_2}{c_1} + \log. x} \cdot \frac{xc_2 - c_1}{c_2 - xc_1}$$

$$\text{and } U = up + u^1p^1 + \ldots. \qquad V = vq + v^1q^1 + \ldots.$$

u, v, p, and q being the velocities and osmotic pressures of the various kations and anions, and the quantities U_1 and V_1 referring to one of the solutions, U_2 and V_2 to the other. c_1 and c_2 are the total concentrations (gramme molecules per litre) of all positive ions in the two solutions respectively.

The formula has been applied to calculate the E.M.F. between two equally concentrated solutions of different electrolytes. The values are mostly small, as may be seen from the following examples:

Normal solutions of	π obs'd.	π calc'd.
HCl, KCl	0.0285	0.0282
KCl, NaCl	0.0040	0.0052

*Historically, the first individual E.M.F. to be determined was that existing at the contact of two different metals. It was calculated, at Edlund's suggestion, by equating the heat given off (or absorbed) per second at the junction while a current passed to the product of current and E.M.F. at the junction. Electromotive forces of this nature are usually very small, as may be seen from the annexed table, giving their value in volts for the following metals against copper:

Table 3.

Antimony	—0.0060
Iron	—0.0031
Cadmium	—0.00061
Zinc	—0.00044
Bismuth	+0.024

The table is taken from *Ostwald*, Lehrbuch, II., 919.

Of these, Nos. (3) and (4) are obviously equal in magnitude, but of opposite sign, and the same is true for Nos. (7) and (8). The possibility of computing the values of the remaining quantities (Nos. (1), (2), (5), and (6), which represent, in each case, individual E.M.F. between metals and electrolytes, has now to be considered.

E.M.F. BETWEEN METALS AND ELECTROLYTES.

It will be readily seen that no process of addition or subtraction of the E.M.F. of various cells will lead to the desired quantities. If, on the other hand, the total E.M.F. of the cell No. (1) (Fig. 3) be known, and, in addition, the individual E.M.F. between the mercury and the electrolyte, then that between the zinc and the electrolyte can be determined by subtraction; and that similarly by measuring the E.M.F. of suitable cells having mercury (with calomel) for one electrode, any other individual E.M.F. of the kind under consideration may be at once determined; or, in other words, that a knowledge of one such individual renders possible a determination of all the rest.

The importance, then, of arriving, by some means, at a measurement of some one individual electromotive force of this nature is apparent: the method suggested is due to the development, by Prof. Ostwald,* of a theorem of H. v. Helmholtz respecting the alteration of the surface tension of mercury by an electrical charge. If a drop of mercury in a watch glass (Fig. 7) be covered by dilute sulphuric acid (to which a trace of potassium bichromate has been added), and an iron wire be passed through the acid so as to touch the mercury, the latter will at once contract, the drop becoming more rounded and its surface correspondingly less. That this phenomenon (increase of the surface tension of the mercury) is brought about by an alteration of the electrical condition of the mercury may be concluded from a modified form of the experiment, the apparatus for which is indicated in Fig. 8.

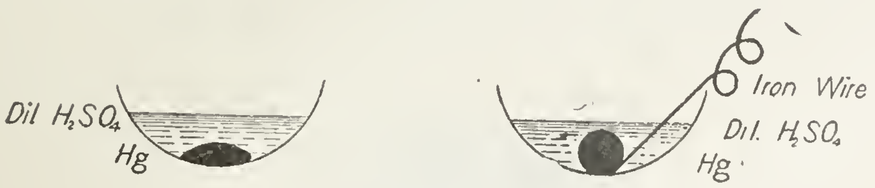

Fig. 7.

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*Ostwald. Lehrbuch, II., 931, 1893 (first published in the first edition of the "Lehrbuch," Vol. II., p. 487, 1887).

This consists essentially of an upright tube, drawn out to a capillary at one end and filled to a certain height (depending on the diameter of the capillary) with mercury, which does not, however, fall through, being supported by reason of its surface tension at the meniscus. Electrical connection is obtained by means of the wire A, and the tube so prepared dips into a beaker of dilute sulphuric acid (one part of acid to six of water). By means of this apparatus any variation of the surface tension of the mercury at C may be very readily observed; an *increase* causing the meniscus to rise in the tube, a *decrease* to lower. It has been observed that the application of an external E.M.F., raising the potential of A relatively to B, causes the meniscus to fall; if, on the other hand, the potential of B be raised with reference to A, the meniscus rises until the potential difference reaches 0.97 volt, after which any further increase causes it to fall.

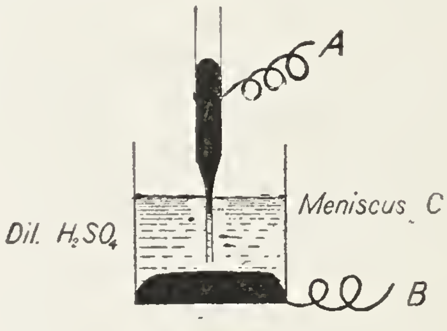

Fig. 8

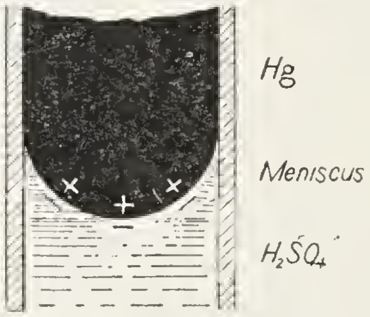

Fig. 9.

H. v. Helmholtz's explanation may be understood by a reference to Fig. 9, which represents a magnified image of the meniscus C of Fig. 8.

**H. v. Helmholtz.* Gesammelte Abhandlungen, I., 855 and 925, originally published in *Wied. Ann.*, VII., 337, 1879.

As the passage of electricity from mercury to sulphuric acid, or *vice versa*, involves the decomposition of the sulphuric acid, which cannot be effected with less than about 2 volts, the surface of separation between mercury and electrolyte under the conditions of the experiment (E.M.F. less than 2 volts being made use of) acts the part of a dielectric, and the charges produced by the (individual) E.M.F. between the mercury and the sulphuric acid collect on the two sides of the meniscus, as in the case of an ordinary electrostatic condenser. The presence of this charge tends to increase the surface of the mercury, *i.e.*, decreases the observed surface tension (*cf.* theory of gold leaf electroscope), and a removal of the charge by means of an external E.M.F. of opposite sign and equal intensity will cause the apparent surface tension to reach a maximum. The observed value 0.97 volt is then the positive potential assumed by mercury in contact with sulphuric acid of the strength employed. Similar measurements with hydrochloric acid as the electrolyte give +0.560 for the potential of mercury against a solution of 36.5 grammes HCl in a litre of water.

If v. Helmholtz's theory of these electro-capillary phenomena be accepted, it furnishes the first individual E.M.F. between a metal and an electrolyte; the E.M.F. of other metals *in contact with normal solution of their salts* (calculated as indicated on page 247) are given in the following table (for a temp. of 15° C.):

Table 4.[*]

Magnesium	—1.22 Volt
Zinc	—0.51
Aluminium	—0.22
Cadmium	—0.19
Iron	—0.06
Lead	+0.10
Copper	+0.60
Mercury	+0.99
Silver	+1.01

The accurate determination of these values (those given in the table have a probable error of about one or two hundredths of a volt) is of the same importance to electrochemistry as is the determination of the atomic weights to analytical chemistry; the table itself is the modern quantitative form of the old "Electrochemical Series" of Volta.

---

[*] *Ostwald.* Lehrbuch, II., 946, 1893.

As the individual electromotive forces of all ordinary voltaic batteries occur at the junction of

(*a*) Metal with metal ;
(*b*) Metal with electrolyte ;
(*c*) Electrolyte with electrolyte,

it is possible from the data given above to calculate the E.M.F. of a large number of cells. For example, in the Daniell's element, the total E.M.F. is made up of

(1) Zinc – Zinc sulphate solution.
(2) Zinc sulphate solution – Copper sulphate solution.
(3) Copper sulphate solution – Copper.
(4) Copper – Zinc.

(1) Of these the first depends on the concentration of the zinc sulphate solution. If this contains 161 grammes $Zn\,SO_4$ per litre ("normal solution"), the E.M.F. will be 0.51 volts with the zinc negative [Table 4], which number will be greater if the electrolyte be more dilute, and conversely. The quantitative relation is given by equation (15*c*):

$$\pi = 0.0002\frac{n_i}{n_e}\,T\log_{10}c + \text{constant}$$

(c being the concentration of the zinc sulphate in solution) the change in value of variable term on the right-hand side being obviously the quantity in question. Thus, diluting the electrolyte with an equal volume of water would change the E.M.F. to

$$0.51 + 0.0002 \times \frac{1.25}{2} \times (273 + 15)\log_{10}2 \quad = \quad 0.51 + 0.0108$$

or about 0.52 volts, the zinc negative, as before.

(2) The second, on account of the approximate equality of the velocities of copper and of zinc [Table 2], will be negligible if the copper and zinc solution has the same concentration; if not, its value may be obtained from equation (18*b*).

(3) The third is similar to the first, for normal copper sulphate solution amounting to 0.60 volts, the metal positive ; increase in concentration of the electrolyte increases this value, and conversely, according to the equation (15*c*), just quoted for zinc sulphate.

(4) The value of the fourth E.M.F. is given in Table 3. It may be neglected in comparison with the others, being less than the thousandth of a volt.

Addition of these four quantities gives 1.11 volts as the E.M.F. at 15° C. of the cell

Zinc | Normal zinc sulphate | Normal copper sulphate | Copper.

and the effect on this quantity of alterations in the concentration of the electrolytes may be calculated as described under heads (1), (2), and (3).

"ABNORMAL" E.M.F.

In contrast to the case of the Daniell's cell, where the total E.M.F. is practically the sum of the two individuals of Table 4, examples may be quoted where the allowance for difference in concentration of the electrolyte (in the case just calculated a mere correction) constitutes by far the largest term. Such, for instance, is the case in the combination*

Ag | 0,1 normal $AgNO_3$ | normal KCl | AgCl | Ag,

whose E.M.F. has been found to be 0.51 volt. This comparatively high value for a cell whose two electrodes are formed of the same metal depends on the fact that the osmotic pressure of the silver ions in the silver nitrate solution is very considerable; while in the silver chloride solution it is extremely small, both on account of the slight solubility of that substance, and because the dissociation of what silver chloride does dissolve is much reduced by the presence of the potassium chloride (see p. 238). When the cell is closed, the effect of the passage of the current is simply to remove silver ions from that solution in which their concentration is great to that in which it is small, and the E.M.F. of the cell will be

$$\pi = 0.0002 \, T \log._{10} \frac{C_1}{C_2}$$

Where C_1, the concentration of the silver ions in the $AgNO_3$ solution, may be set (assuming complete dissociation) 0.1; while C_2, their concentration in the silver chloride solution, which, in the absence of potassium chloride, has been found† to be approximately 1.1×10^{-5}, is reduced by the presence of that salt to $(1.1 \times 10^{-5})^2 = 1.21 \times 10^{-10}$. Substituting these values, the calculated E.M.F. of the silver cell at 15° C is

---

* *W. Nernst.* Thereotische Chemie, Stuttgart, 1893, p. 569.

† *Kohlrausch and Rose*, Loeslichkeit schwer loeslicher Koerper, *Z. Ph. Ch.*, XII., 234, 1893, have estimated the solubility of silver chloride in water by determining the electrical conductivity of its solution, and calculating m (the quantity of salt dissolved) from the known velocities of the ions $\overset{+}{Ag}$ and $\overset{-}{Cl}$ by means of the equation:

Conductivity $m = (u + v)$. See page 232.

$$\pi = -0.0002 \times 288 \times \log._{10}(1.21 \times 10^{-9}) = 0.52 \text{ volts}$$

a result which agrees sufficiently well with the observed value 0.51 volts.

An analogous explanation may be offered for the "abnormal" behavior of silver in a solution of silver potassium cyanide.* In a cell of

Silver | Silver-potassium cyanide | Lead nitrate | Lead

not only does the E.M.F. observed bear no apparent relation to that of silver against lead in a solution of their nitrates, but its very sign is changed; and whereas in the latter case the lead is negative with reference to the silver, in the cyanide cell it is the silver that dissolves. "Abnormal" cases such as this, which have contributed largely to the overthrow of the older electrochemical theories, and which seemed to argue against the possibility even of a definite order for the metals in the "Electrochemical Series," may, by means of the methods explained in this paper, be brought under the same category as the others, and their E.M.F. may be calculated without the introduction of any new hypotheses.

In this paper, an endeavor has been made to show how the introduction of the conception of "osmotic pressure" in conjunction with the first and second main principles of thermodynamics has led to the evolution of a theory of solutions, which includes a quantitative account of the relations existing between phenomena so diverse as are the vapor tension, freezing and boiling points of solutions, their electrical conductivity, and its dependence on dilution, and the alteration in their concentrations produced by the passage of a current, and which lends itself to the solution of problems in connection with the E.M.F. of various voltaic batteries in a manner as accurate as it is simple and straightforward. It must not be supposed, however, that more than a mere sketch of the subject has been attempted, or that even the points of contact between the new theory and the electrical phenomena have been extensively reviewed; the temperature

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*Such a solution contains extremely few $\overset{+}{Ag}$ ions. See *Leblanc and Noyes*, Ueber vermehrte Loslichkeit, *Z. Ph. Ch.*, VI., 397, 1890.

the form

co-efficient* of the E.M.F. of cells, electrical conduction and electrolysis†, in mixed salt solutions, the phenomena of galvanic polarization‡, and the common experiments§ grouped by Ostwald under the title of "Chemical Action at a Distance," have been, and are at present, subjected to a searching and successful investigation by the aid of this modern scientific instrument, the product of a fortunate combination of wide-reaching experimental generalizations with the rigid laws of Energetics—of the genius of Faraday with that of Clausius.

I desire to take this opportunity of expressing my thanks to Dr. W. L. Miller and Mr. T. R. Rosebrugh for much valuable assistance in writing this paper.

---

*For many cases this may be determined by the differentiating formulæ for π given in this paper ; for example, equation (15*b*).

†*W. Hittorff.* Pogg Ann., ciii., 45, 1858 (Electrolysis of mixture of K Cl and KI). *H. Freudenberg*, Neues Prinzip der Elektrischen Trennung von Metallen : Ber. d. deutsch. Chem. Ges., 1892, 2492.

‡*M. Le Blanc.* Die Elektromotorischen Kräfte der Polarization, *Z. Ph. Ch.*, VIII., 299, 1891.

§*W. Ostwald.* Chemische Fernewirkung, *Z. Ph. Ch.*, VIII., 541, 1892.

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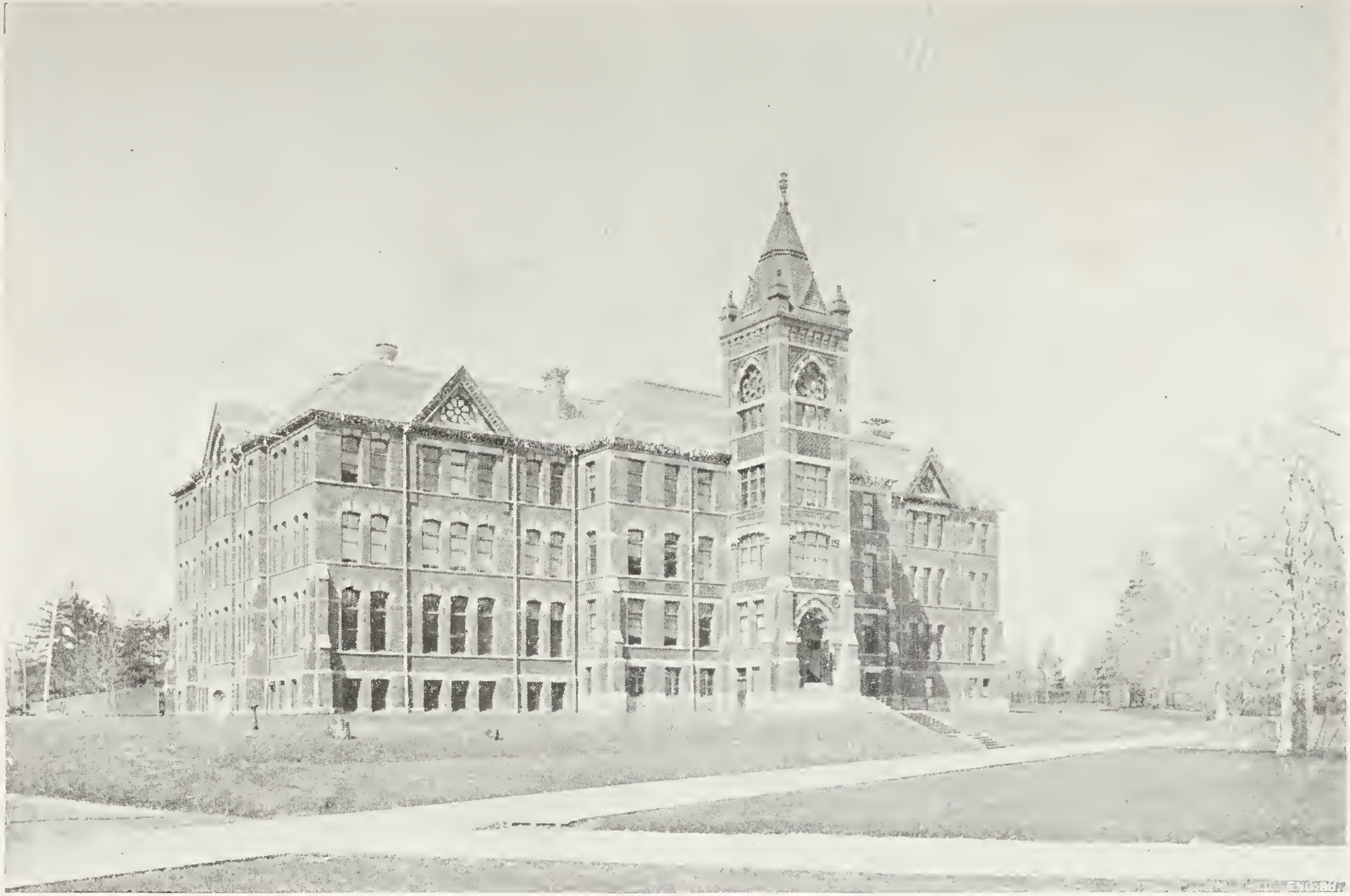

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PREFACE

The proceedings of the Engineering Society of the School of Practical Science, now in its eleventh year, are herewith presented.

The contents of this issue will be found of great interest. It will give many helpful suggestions to students as well as to men already at professional practice, and will convince our readers that the members of the society take a lively interest in the opportunities presented to them by its semi-monthly meetings.

The paper on "Roentgen Radiation," by Mr. McLennan, will show that our institution was not in the least behind others, but in most respects exceeded them in the success of their experiments with the noted "X" rays.

Special attention is called to the masterly work on the "Pendulum," conducted in the laboratories of the School by Mr. Scott. This won for him the 1851 Exhibition Science Scholarship awarded by the University of Toronto.

A marked feature of the issue is the original work on Cements, and on Brick Piers. Several new inventions are also presented.

The present edition consists of 1,500 copies.

All of which is respectfully submitted.

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Carter, W. E., '98.
Chaplin, G. W., '98.
Charlton, H. W., '97.
Collins, C. D., '98.
Darling, E. H., '98.
Dawson, R., '98.
De Cew, J. A., '96.
Elliott, H. P., '96.
Fisher, A. M., '98.
Fitzgibbon, R. G., '98.
Gordon, C. B., '98.
Gray, A. T., '97.
Gray, J. M.
Grant, W. F., '98.
Gurney, W. C., '96.
Gzowski, C. S., '98.
Haight, H. V., '96.
Henderson, D. R., '98.
Hicks, W. A. B., '97.
King, C. F., '97.
Kormann, J. S., '98.
Laing, W. F., '96.
Macbeth, C. W., '96.
Macmurchy, J. A., '96.
McNaughton, F. D., '98.
Mackintosh, D., '98.
Mackenzie, G. C., '98.
McMichael, C., '98.
Martin, Tom, '96.
Morphy, E. J., '98.
Morrison, H., '97.
Perry, F. M., '98.
Piper, A. G., '98.
Proudfoot, H. W., '97.
Richards, E., '97.
Robinson, A. H., '97.
Roper, W. P., '98.
Sanderson, A., '97.
Scott, W. F., '97.
Shaw, J. H., '98.
Sheldon, S., '98.
Shipley, A. E., '98.
Shipe, R. R., '96.
Smillie, R., '97.
Smith, R., '98.
Smallpiece, F. C., '98.
Stacey, G. E., '97.
Stovel, H. R., '98.
Stull, W. W., '97.
Troupe, W. J., '97.
Tye, C. H., '98.
Vercoe, H. L., '97.
Webster, E. B., '96.
Weekes, M. B., '97.
Weldon, E. A., '97.
Willson, R. D., '98.
Wilkinson, T. A., '98.
Williamson, D. A., '98.
Wright, T. D., '96.

ENGINEERING SOCIETY

OF

The School of Practical Science

TORONTO

PRESIDENT'S ADDRESS

Gentlemen,—It is with great pleasure that I welcome you to this the first regular meeting of the Engineering Society.

I have to thank you most sincerely for the honor you have conferred upon me, the highest in the gift of the Society. It has been said by each president in turn that he feels entirely incapable of carrying on the work of his able predecessors, and I feel as keenly as they my incapacity to fulfil the onerous duties which devolve upon me. When I look back at the names of those who have in turn filled this chair, I cannot but feel my inability to attain to their standard of excellence. Among those who have led this Society none have surpassed Mr. Shields and Mr. Blackwood, to whom I looked up as a freshman and a sophomore. It is in the footsteps of such men as these that I have to follow. The task is a difficult one, yet be assured that I shall strive to perform it to the best of my ability. And I feel almost secure in promising this when I consider the personnel of the committee you have selected, composed as it is of energetic, enthusiastic students, who will doubtless do everything in their power for the advancement of the Society's interests. It is with great regret that we have been forced to accept the resignation of two of the best men on the committee, R. G. Black, fourth-year representative, and

C. L. Lawrie, treasurer. These gentlemen are now filling lucrative positions, and, while regretting our loss, we are pleased at their good fortune.

But, gentlemen, you must remember that the committee, no matter how capable, cannot make this Society a success without your hearty co-operation. It is not infallible, and when we act contrary to your wishes do not fail to draw our attention to the fact. It may be an expression of confidence to allow our actions to go unchallenged; but, on the contrary, such want of criticism may indicate on your part a lack of interest in the Society.

Let each one make himself thoroughly conversant with the details connected with the organization and working of the Society, and if such a course be pursued our meetings will never lack interest and enthusiasm.

A hearty welcome is extended to the many new members who are with us to-day. Last year the proportion of first-year men attending the meetings was large; we hope the present first-year will follow their excellent example. For the benefit of those who are present for the first time, it might be mentioned that the Society meets every other Wednesday, at 3 p.m., to discuss matters of general interest in engineering and kindred subjects, and to hear papers read based on topics which may be useful to us in our profession. Ample opportunity is also given for free discussion and interchange of ideas. These meetings are virtually part of the regular course of the School—minus an examination. The draughting rooms are closed, no lectures are given, every student is expected to wend his way to our gatherings and listen with such interest or patience as he can command to the instructive or heavy paper which may be before the meeting. And though the paper may not always be on your special line, or entirely within your grasp, still there is always the educative value of intercourse with one's fellow-students.

The students of the School of Science have the name of being loyal to their colors, and always exhibiting a true college spirit. This, gentlemen, is most desirable, and we trust we shall always possess the *esprit de corps* which has been so useful to us in the past. But in order to work well together we must know each other, and these meetings are almost the only medium for bringing the four years together.

In addition to the benefits which are to be derived from the Society's meetings, there are also the advantages of an excellent library, where is to be found, in ever-increasing number, such books as engineering students or engineers require. In the library are also kept the leading engineering papers and magazines of the day. We hope that some arrangement will soon be made so that these will be accessible at any time, and not at certain hours as at present.

The Society has been steadily growing in influence and interest since its inauguration, under the able guidance of our worthy principal, Professor Galbraith. Every year there has been an advance over the preceding, the past year being no exception. A larger number of papers were read, and the general interest taken in the meetings showed how much the work of the Society was appreciated. Of the eighteen papers read eight were contributed by undergraduates, three from the second-year and five from the third. These eight papers, though they may not be of surpassing value to the literature of the day, were, however, of great value not only to the Society, but also to those who have written them.

The authors of the papers derive the greatest benefit; each one chooses a subject in which he has some especial interest; and long before the paper is finished he finds many points in which his knowledge is insufficient, and so investigates further to obtain the necessary information. When the paper is ready to be presented he has become very much better acquainted with his subject, and is able to lay before his hearers in a clear and concise manner the information thus gained. Allow me to say that there is nothing to hinder any of you from writing on some subject which has come under your notice. You will be amply repaid for your labor by the knowledge you yourselves gain, and by the interest your fellow-students take in your efforts.

There is yet another inducement, one which is or should be of secondary importance, but which nevertheless is of great value to the Society. I refer to the action of the Council in giving marks for each paper read, the maximum being 100; all marks over 50 are considered in granting honors. But you may say you do not intend to write for honors at the examinations; nevertheless we shall be glad to hear from you in the line of original contributions, for, as has been said before, the marks given are of but little value in comparison with the information and experience gained in writing the paper. Of the eight undergraduate writers last year, only three were honor men.

Gentlemen, some of you may not feel inclined to write a paper, but burn with a desire to address the Society. For that and other reasons, I would strongly advocate the introduction of debates. We are attending the School of Practical Science; it sometimes seems as if we are so intensely practical, so matter of fact and prosaic, that it is impossible for us to adequately express our ideas without the use of draughting boards, rheostats, transits, or telescopes. It may not be expected of the student of the School of Practical Science to soar aloft on the wings of oratory, as do his brethren in the non-kindred course of Political Science; yet it is to be expected that men are to be found here who can maintain the honor of the School on any platform. We send two men each year to debate against 'Varsity; why should they go untrained, comparatively speaking, any more than that men not fleet of foot should be sent to carry our colors in a "team race"?

We should take every opportunity of gaining ease and confidence in public speaking, for it is only by constant practice that we shall be able to speak fluently and intelligibly. In our professional life we will come in contact with men of knowledge and experience who will frequently judge us by our power of expression. Naturally, when practising here we may have to put up with many a jesting remark or good-natured joke, but such should only serve to spur us on to renewed and more perfect effort.

Before we parted last spring, pamphlet No. 8 was distributed, thanks to the untiring efforts of the editor, Mr. Angus. The pamphlet was a large one. The plan of sending out, in advance, copies of the papers to be read worked admirably, and contributed largely to the success of the meetings. I trust that this plan may be continued, for by it the writers of papers may bring their views on any subject promptly to the notice of the profession, and not six months or a year after the paper has been written.

The pamphlet was a large one; we looked at it admiringly, and, as we noted its size and scanned its pages, each of us felt proud of our Engineering Society. The sky was clear, not a cloud in sight, nothing, in fact, to mar the serenity of all concerned. And so, at first, thought the committee to whom you intrusted the management of your affairs. But soon a cloud appeared no bigger than a man's hand; someone hinted at money! This vague hint troubled us little; we looked back on our track, we saw the pamphlet, large and entertaining, and felt confident. But the cloud grew as we looked, and the pamphlet, large and entertaining, grew, as we looked, larger, but less entertaining. The cloud spread, soon the whole heavens were overcast. We scanned the horizon; away in the distance appeared havens of safety, but the storm was fast coming up. We faced it bravely, but shuddered when it broke, for there burst on our devoted heads a thunderbolt—an account for $580.08. Gentlemen, we did not despair, but set to work with a will. One hundred dollars was the sum total of the cash in the treasury; $225 followed from advertisements, collected by the persevering efforts of the treasurer; and finally $50 came from the government, making in all $375. We breathed more easily, but felt somewhat heavy-laden, being still $200 short.

Naturally the question arose, Where was the money to come from? We could count on this year's membership fees of $100 or more, but against that had to be placed the running expenses of the Society, postage, printing, library, etc., which last year amounted to $110 We endeavored to obtain cheap postal rates for the distribution of the pamphlet, but failed. We interviewed a minister of the government, and when he understood the state of affairs he very kindly granted us $50 nominally in payment of pamphlets already distributed among members of parliament. On May 7th a letter was issued to our graduates asking for subscriptions; to this we received but few replies. Two months and a half later, July 25th, we issued another letter, stating fully our position and asking aid. Many of the graduates responded liberally, and none more so than those who are now with us as Lecturers or Fellows. Up to date we have received $65, and now we take the opportunity of thanking the graduates who so generously came to our assistance.

But, gentlemen, there is still a deficit. We have done all in our power for the Society, and, as a last resource, have fallen back on our undergraduate members. The Society has heretofore been dealing, philanthropically, in draughting material, giving the students the best of imported paper at cost price. The price has been slightly increased, so as to yield us a revenue. With this added source of income, a reduction of running expenses along with a few more subscriptions, we hope that by the end of the college year our accounts will show a slight surplus.

But what for the future? Evidently there must be a change in our financial methods. One of our graduates remarked: "'Out of debt, out of danger,' is a good and safe maxim, and one I recommend your financial committee to adopt. Anyone can do wonders with money, but the sharp business element is that which enables one to do much with the money in hand." The advice is good; we would do well to follow it. Our ordinary running expenses cannot be curtailed to any great extent. The expenditure on the pamphlet is where the change must be made; funds must come in from new sources if it is to be kept up to the size of No. 8. But is this a necessity? Must we publish all the papers read? Or, should we make a selection, as was done in former years? Then there is the question of advance proofs; that is an additional expense, but, if at all possible, I would strongly advocate the continuance of this plan, which worked so successfully last year.

It has been suggested that graduates and undergraduates should each pay forty or fifty cents for the pamphlet. I think, however, that the latter should receive the pamphlet free, as in the past. As to the graduates, I am of the opinion that they would be quite willing to pay a small amount for a publication which is well worth the money, especially when they know they are assisting the Society of their old *alma mater*. However, these and other points will doubtless be fully dealt with during the coming term.

Before leaving the question of finance, we wish to express our sincere thanks to the Alumni Association of the School, especially to the president, Mr. James McDougall, and to our genial friend the secretary, Mr. A.T. Laing, for their efforts on our behalf. Upon hearing the condition of our finances, they very kindly issued a letter to the members of the Alumni Association—who are also members of the Engineering Society—asking them to aid us in every way possible. We have no doubt that their appeal helped us very materially.

The last three years have been active ones in the history of the Society. Our regulations are not "like the laws of the Medes and Persians, which change not," for many an amendment, or amendment to the amendment, has been made to such and such an article of our constitution, until now some of the articles are exceedingly cumbersome. Would it not be advisable to have the constitution thoroughly revised by a small committee, the result of its deliberations to be submitted to the Society for its approval?

Notice of motion has already been given the Society of still another change in the constitution, viz., to transfer the office of editor-in-chief from the fourth-year to the graduates' representative. This is a motion of considerable importance, and requires serious consideration.

While still of the opinion that "member of the Engineering Society" and "student of the S.P.S." should be synonymous terms, and that the Society should be the mainstay of everything of interest to the student, yet, from financial considerations, it may be advisable that such a controversial subject should be held over for consideration at some future time. Yet, whether or not the terms are synonymous in theory, they are so in fact. We are a separate body in university life, and it should be the aim of everyone of us, as without doubt it is, to make the name of the S.P.S. both feared and respected in college and campus.

Many pleasant letters have been received from our graduates, and from professional men not graduates, speaking very highly of our latest publication, and such praise we take as no small testimony to its value.

May such expressions of appreciation spur us on to greater efforts in the future !

Several interesting papers have already been promised for the coming term. As to the subject-matter for a paper, the opinion of one of our graduates, now a busy engineer, fully covers the ground : " Make the papers essentially practical, avoid too much theorizing, get at what a man will meet in practice, and the rest will turn up in hundreds of magazines and scientific papers published as business concerns."

The librarian has on hand, for distribution, copies of nearly all our previous pamphlets. These volumes are full of information. Every student should examine them for himself ; for he will find much that is of direct practical importance in them, papers bearing almost directly on work set down in the curriculum, such as " The Fundamental Principles of Mechanics," " Diagrams," " Hydraulic Cements," "Notes on Cements," " Hirn's Analysis," " Frieberg's Smelting Process," etc.

Before taking my seat, I wish to refer to the recent appointments to the staff of the School, namely : W. E. Boustead, Demonstrator in Metallurgy and Assaying ; W. M. Minty, Fellow in Mechanical Engineering ; and last, but not least, one who is well known to you all, and who formerly filled the president's chair with so much energy and ability, A. E. Blackwood, Fellow in Electrical Engineering.

On behalf of the Society, I congratulate these gentlemen on their appointment.

Gentlemen, I trust that we shall have a profitable and instructive year, and that we shall all be worthy of and live up to our college motto,

" *Scite et Strenui.*"

Toronto, Oct. 16th, 1895. G. M. CAMPBELL.

ILLUSTRATIVE CASUALTIES IN THE WORKSHOP

By Cromwell Gurney, '96.

In nearly every shop the details of all accidents, particularly those resulting fatally, are suppressed as far as possible, and this suppression results in the dangerous part being left unprotected, even after the casualty due to a want of protection has occurred. For this reason a brief outline of some common accidents that are happening every day may prove of use to men whose vocation calls them to a constant handling of all kinds of fast-running and so-called dangerous machinery Every accident resulting in injury to a human being should be reported to the factory inspector, but in a large establishment the foreman in whose shop the accident occurs usually leaves it to the superintendent, while he, the superintendent, leaves it to the foreman, and in this way it is never reported at all.

There are more casualties reported as occasioned by circular saws than from any other one type of machinery, and, for this reason, too much prominence cannot be given to the danger of carelessness in handling them.

Sometimes it happens that no one is to blame when a fatality occurs, as when a circular saw breaks, as shingle saws and veneer saws are liable to do, being necessarily very thin and running at a very high rate of speed. All circular saws should be made of the best crucible or finest silver steel, and should be carefully and uniformly tempered throughout, requiring great skill and watchfulness on the part of the temperer. Great care is also required in hammering out these saws, as often the process forces the strain to one part, causing a slight bulge, which may crack when some unusual strain is put upon the saw. The crack relieves the strain caused by the bulge, and by boring a small hole at the terminus of the split it will go no farther, the saw being safer than before the fracture occurred. In using a rip saw a wedge should always be inserted behind the saw, in order to keep the cut open, that the wood may not bind the saw. A terrible example of this neglect came under the writer's observation. A clumsy hand was pushing a large piece of lumber upon a saw so fast that the machine almost stopped. At this moment the damp wood bound the saw, with the effect that the heavy lumber was shot, end on, into the man's chest, mutilating him horribly. Most of the accidents, however, are not due to imperfect saws, but to carelessness in the employee, who, as a rule, loses his fingers as a penalty.

Generally speaking, the circular saw is always dangerous when in motion, and care is needed on the part of the attendant when operating any style of saw machine; but there are adjustments or adaptations of saws much more dangerous than others. Those running through a slot in the table are perhaps the most harmless as regards cutting accidents, while those overhanging their frames, and projecting out, are the most dangerous. Of the many guards devised none are free from objection, for one reason or another. Sometimes a hammer or wrench, left on the table, will be jarred until it comes into contact with the teeth of the running saw. As the teeth are unable to bite through the metal of the wrench or hammer, the saw itself breaks, sending its fragments with fearful velocity, as may be judged by one case, where a large piece of a saw was buried completely out of sight in a neighboring post.

As to covering or guarding all saws, it is impracticable, without very much interfering with the quantity of work turned out.

The floor about the neighborhood of a naked saw should be kept altogether free from obstructions which would be likely to cause stumbling, as to stumble against a running saw means horrible mutilation.

In using both emery wheels and saws, the operator should stand slightly out of the plane of the wheel, which puts him out of range, so to speak, if any accident should happen.

Next to the saw in degree of danger is any machine with more or less exposed gears. Machines used for reaming and tapping steam fittings, such as elbows, are a perfect maze of gears, and consequently are considered very dangerous. According to law such machines are supposed to have their gears protected, but this is impossible in many cases, or, perhaps, the upper half of a gear wheel is shielded, while the lower is exposed, which gives the operator a false sense of security. While operating this class of machinery every part of the garments should be buttoned up snug, and no loose or ragged sleeves worn which might catch and draw the hand or arm in.

No gear machine should be lubricated while in motion, as it is by this means that many a catastrophe occurs, as happened in the case of a man who was drawn into the underside of the cogs on the crown wheel of a water wheel. It was supposed that he was oiling the bearings.

Another source of a great many disasters is carelessness in handling running belts. Some advantage may be derived by a review of several typical examples of accidents caused by belts.

One peculiar accident, resulting only in a badly frightened youth, might be here mentioned. The particular youth in question desired to see how close he could stand to a fourteen-inch driving belt. The belt, however, owing to a violent fluctuation of load, gave a quick fling, and the overlap where the joint was made caught in some portion of his apparel, with the effect that he was whisked off his feet, and rapidly borne toward a three-inch opening in a brick wall, through which the belt disappeared. When he reached the hole in the wall, like a flash of lightning, every rag of clothing he possessed except his boots was wrenched off, and he dropped helplessly to the floor, very much shaken, but otherwise unhurt.

Great care should be exercised in putting a belt on a running pulley, as this operation causes many accidents. Every year there are the usual number of broken and dislocated arms reported from this cause. The reason of this is apparent at once to anyone who has felt the tremendous and sudden wrench when a fast-running belt starts unexpectedly while it is being put on.

The most significant fact in all belt accidents is that the victims are not, as a rule, green hands, but old and skilled mechanics and engineers, whose familiarity with machinery has made them careless.

A belt should never be held upon a pulley with the foot, as there is great danger of the boot getting caught in the joint of the belt. Neither should one be held on by a piece of wood held loosely in the hand, as the stick wrenched from the hand might strike the face or head of the holder.

The iron foundry is correctly given the credit, or perhaps it should be discredit, of being one of the most dangerous departments of modern manufacturing establishments. On a sultry July day, when the thermometer near the cupola registered 140° Fahr., the writer has seen four men, one after another, receive burns more or less dangerous. The extreme heat creates a recklessness in the men which sometimes results disastrously. Nearly all these accidents occur from a careless man slopping the iron from his ladle on to his mate's foot, or perhaps the carelessness in the victim himself, who steps backward against a ladle of molten metal. If the melted iron strikes a smooth surface, it rolls off and does no harm; but, as a rule, the moulders wear lace boots, and the metal lodges in the laces and burns to the bone before the boot can be removed.

In a moulding room, all obstructions which might cause the men to stumble while carrying the iron must be removed, as a bad stumble by one of the men carrying a 300-lb. ladle means a painful accident to both his mate and himself.

Some time ago a peculiar incident happened in a large American foundry. The brickwork through which the tap-hole was made completely gave way, allowing the whole fluid contents of the cupola to come seething out. The hot iron, striking some water in the sand, flew to great distances, setting fire to the roof of the building in a dozen places. It was only by incredible activity on the part of the employees that the building was saved. In this case but one life was lost; the melter was standing with his back to the cupola, and so had no chance to make an effort to escape. Nearly every man in the whole shop was more or less burned by the flying metal, while of the unfortunate melter there remained but a few charred bones.

It is only of late years that people have wakened up to the real danger of spontaneous combustion. If a piece of waste that has been used for wiping up linseed oil is left in the sun for a very short time, it will nearly always ignite of itself, so that any carelessness in leaving oily waste about is very dangerous. Another source of spontaneous combustion is from a painter who, having used a pair of overalls in an atmosphere of benzine and turpentine, rolls them up tightly and puts them into a drawer. In nine cases out of ten, if the above painter came back to look into the drawer within five or six hours, he would find his overalls smoking.

In some large factories the oil room is in a cement vault, and hence is quite safe; but where a wooden shed is used, the floor becomes so saturated with oil that it would ignite at a comparatively low temperature. In such a case some kind of a chemical fire extinguisher should be close at hand.

The explosive qualities of naphtha are sufficiently well understood to need but slight notice here. However, it might be mentioned that if a warm piece of waste, saturated with naphtha, be carried in the hand through the air, it will leave a trail of naphtha vapor behind it, along which fire will travel till it comes to the saturated waste itself. This same thing applies to gasoline also. In some works benzine is used to thin the varnish. Then, if the varnished article is baked in an oven to which the air has access, there might be an explosion. If the temperature of the oven is unduly raised, and then allowed to drop again, the gases in the oven contract, drawing into the oven a supply of air, which, mingling with the vapors of benzine, forms a terribly explosive mixture if ignited. In the neighborhood of a hot oven this ignition is very likely to occur.

Occasionally we hear of a death from asphyxiation, caused by inhaling the hydrocarbon vapors issuing from the tail pipes of petroleum refining stills. However, of late years, these vapors have been trapped and carried into the air by means of a ventilating pipe. So virulent are the above fumes that a single full breath, where they are present, has been known to produce unconsciousness. The fumes of naphtha being two and one-half times heavier than air sink rapidly when liberated, passing under doors and down stairways to the basement, where if they reach a burning gas jet an explosion occurs.

An interesting and instructive accident happened about three years ago in this city. A man in a cleaning and dyeing works was cleaning a silk dress by immersing it in a vessel containing benzine. The vapors at once took fire, and the man was so badly burned that he died within ten days. There was no fire in the room, nor, so far as could be learned, within sixty feet of him. Could it not be that an electric spark, produced by the friction of the silk, as it was immersed, ignited the vapors? This theory would seem to be supported by the fact that if a piece of waste, saturated with benzine, be held in the neighborhood of a fast-running belt, the static discharge will almost invariably ignite the benzine.

Several fires have been caused by the fact that the water pipes are at a different potential difference to the gas pipes, or *vice versa*, as sometimes occurs owing to stray currents from the electric street car service. A case of this kind occurred where there were two pipes about one inch apart, and both paralleling an elevator shaft. The potential difference across these two pipes must have been considerable, for, whenever the elevator went up, the jarring of the two pipes caused a brilliant spark to leap from one to the other. As one of the pipes was used for conveying illuminating gas, and was partly eaten into by the spark when discovered, the danger from fire must be apparent, for had the spark damaged the pipe sufficiently to allow the gas to escape it would have been instantly ignited by the same spark, and in all probability the building would have been burned.

Do not these foregoing examples seem to indicate that foresight is a quality that should be conspicuously present in all good mechanics and engineers?

LIGHTNING ARRESTERS

H. P. Elliott, '96.

The problem of obtaining an efficient protection against damage by lightning has been before the operators of electrical machinery ever since it came into use. From the first it was noticed that, during thunderstorms, charges of static electricity travelled along the wires which were used to convey current from power stations, telegraph instruments, and other electric apparatus.

A coil of wire offers more resistance to a static charge or varying current than it does to a direct current. This is due to what is known as self-induction. It is known by theory, and borne out by experience, that when a static charge passes through a coil, E.M.F.'s, which tend to oppose its flow, are formed in the same way as the induced currents in a coil of wire placed near another coil which is traversed by an alternating current.

Most electrical apparatus contain coils of wire which offer high resistance to the passage of static charges, so that they find less resistance in piercing the insulation of the wire than following the successive convolutions.

Although this of itself may do no serious damage as far as burning or shattering the machines, it short-circuits the coil, and renders it useless, and in the case where it conveys a heavy dynamo current very great damage may be done.

The telegraph instruments were the first to suffer from this. Sometimes, however, instead of springing through the coil, and short-circuiting it, the electricity would spring off the line to water-pipes and other metallic objects connected to the earth. When this took place, it was noticed that the instruments were not damaged. The idea of the first lightning arrester was evolved from this. A point, or several points, were connected with the live wire just before it entered the instruments, and these points were placed near others connected with the earth, so that it was supposed the charge would pass to the earth through these rather than through the instruments. This was generally found to be the case, but very often the lightning ignored the path to earth, and damaged the instruments, as before. This spark gap is the main principle of all lightning arresters of to-day, and on telegraph lines and circuits of a similar nature they are of essentially the same form as the primitive ones.

When a lightning arrester is placed on a circuit used for supplying arc lights, incandescent lights, or current for anything that requires a high potential, the arrester must consist of more than the simple spark gap. You all know that in a circuit like this the potential is many volts above that of the ground. I mean by this that, if the circuit is connected to the ground, current will flow back to the generator through numerous leaks in the wire, or perhaps through another ground connection, or the frame of the machine itself. The amount of this current depends on the resistance it has to encounter, and in many cases may amount to a short circuit on the dynamo. It is found that when the static charge leaps to earth over the spark gap, the current from the dynamo will follow it; arcing between the points, and forming a dangerous ground or short circuit, which blows the fuses and interrupts the operation of the machine for the time being.

Naturally, the first improvement sought for was something to prevent the dynamo current from following the lightning discharge. The first device used was a fuse placed somewhere in the ground connection. This fuse would be blown before the main circuit fuse was affected, the circuit thus remaining unbroken. This answered the purpose very well, but as the fuse had to be replaced after every discharge further improvement was necessary. A New York firm manufactures arresters upon this principle, but they are each provided with eleven fuses, arranged so that when one is blown another is immediately placed in circuit.

There are a great many arresters that depend upon a mechanical device to break the arc. Most of them have an electro-magnet, which is energized by the current when it cuts across the spark gap; the magnet attracting an armature which breaks the circuit. It is easy to see that these will get out of order unless given constant attention; and, in any case, they are gradually destroyed by the heavy ground, no matter how quickly they may stop it. If they get out of order there is generally a brilliant display of fireworks for about three seconds, and the arrester is reduced to a lump of copper.

A very great improvement upon the mechanical device was made by utilizing a well-known property of a magnet—that of repelling an arc.

The spark gap is formed of two metal wings, which are close together at one point, and slope away from each other till there is a space of several inches between them. The wings are placed between the poles of a powerful magnet, so that the arc is blown from the narrow space outwards, until it breaks. These arresters work very well. I had an opportunity of seeing them in operation in a power house equipped by the Canadian General Electric Company. They required little attention but when either the wires were set too close together, or if any dirt collected between them, they would sometimes not break the arc.

It might be well, before going further, to say something about the way lightning gets on the wires, and how it travels along them. Probably the greatest authority on the subject of protection from lightning is Mr. Alexander J. Wurtz, of the Westinghouse Company, whose thorough technical education has enabled him to far outstrip all other investigators. I have noticed, while in a power house, that although the arresters usually discharge when there is a big flash of lightning, they often do so when no flash is seen, or when it is too far away to have struck the wires directly. The arc lamps were often what the men called "struck by lightning," but, upon examination, they bore no traces such as we would expect to find had they been struck. They would have one or more of the coils burned out, just as when the coil is short-circuited. A transformer, said to have been struck, merely had one of the coils burned out, and neither the iron case nor the pole had any marks. Whenever there was an extra large flash of lightning during the storm, and the arrester discharged, the men employed in the power house would say the lines were struck at such and such a point; but I never saw a part where the wires appeared to have been injured, or the insulation burned off.

These facts seem to show that the lines are seldom or never struck directly, and Mr. Wurtz gives the following theory as the one that is most probably correct. The atmosphere, especially during thunderstorms, is found to be at a potential different from the earth, and increasing as we go higher, so that at a height of 1,000 feet a potential of 10,000 volts has been measured. It is not probable, however, that the atmosphere surrounding the lines is under sufficient strain to cause the wires, which are electrically a part of it, to discharge to the earth over the stop gaps. The lightning discharge, whether from one cloud to another or to the earth, is of an oscillatory nature. There are, in fact, as many as ten or more discharges until equilibrium is restored. These discharges will have an inductive effect on the wires and the atmosphere surrounding them, causing waves of high potential to travel along them to and fro, so that now one point and now another is under tension and tends to discharge. These waves also combine and form greater ones, and if they meet a resistance, such as a choke coil, field-magnet coil, or transformer, will pile up at these points, so that the tension is enormously increased. If the wave, on piling up in this manner, cannot flash off to something connected with the earth, it may be reflected back, but is very likely to pass through the coil by the path of least resistance, which is, as was explained, through the insulation.

From this it will be seen that the lightning arresters will not always protect the apparatus. A wave passing along the line may not be great enough to cross the spark gap, but may increase in size and cut through the insulation at some other point on the line. The arrester, in other words, does not arrest, but merely offers an opportunity for the charge to pass off. The spark gap, then, must be arranged so that it will be at a point where the tension is high. There are two ways of doing this: one is to have the gap just before the coil; the other, to have arresters placed at intervals all along the lines. The former method has been used for a long time. The arresters were, in most cases, a continuation of choke coil and spark gap, and were placed either as near as possible to the place where the wires entered the power house, or on the machines themselves. The necessity of having arresters distributed along the lines has only recently become known.

The ideal lightning arrester must be very simple in construction, with no moving parts to get out of order, and must last throughout a great number of discharges; for, when out upon the lines, it cannot receive much attention. It must be cheap, so that a large number may be used. The spark gap must have a very low inductive resistance; but must prove an effectual barrier to the dynamo current, so that it may discharge very easily and before damage is done elsewhere. An arrester fulfilling these conditions would be very far in advance of any of those described, and such a one *has* been constructed. I think you will agree with me in saying that it approaches very nearly to the ideal.

Mr. Wurtz, in studying the behavior of lightning, and trying to get an efficient arrester, found that certain metals, zinc, bismuth, antimony, cadmium, and mercury, would not, under certain conditions, sustain an arc due to an alternating current. He uses in his (lightning) arrester seven cylinders made from an alloy of the above metals. Each cylinder is $\frac{3}{4}$ in. in diameter by $1\frac{1}{2}$ in. long, and the seven are fastened, side by side, on an insulating block, with a space of $\frac{1}{64}$ in. between each. The outside cylinders are connected to the circuit wires, and the centre one to the ground; the discharge passing readily between them. These arresters can only be used for alternating currents, and the above form is suitable for 1,000-volt circuits. For 2,000 volts two arresters can be coupled together, and so on, up to 10,000 volts or more.

For use on direct current circuits, Mr. Wurtz has designed an arrester which works on a different principle, but is equally efficient. He noticed that a static discharge would take place much more readily over a surface such as smooth glass, wood, or marble than through air; also that if the electrodes were joined by a lead pencil mark or a charred groove on the surface, the distance across which the charge would spring would be much increased. It is known that the electric arc is caused by the current being conducted by the vapors of the electrodes, and that if these vapors could be suppressed there would be no arc. Combining these two principles, the following (method) was evolved: The two electrodes are placed three-eighths of an inch apart on the surface of a block of wood, on which several shallow grooves are burned, joining them. Another block of wood is placed over these, and screwed tightly down. By this means a very low resistance is offered to the discharge, although the gap is wide; moreover, the electrodes being covered, there is no chance for the vapors to form a conducting path from one to the other.

After a discharge has taken place on the metallic arrester, there is only a slight pit or burn on the cylinders, *so they will last for practically an indefinite time.* The arrester for direct current circuits gave some trouble at first, as a cavity was soon worn in the wood by the static discharges; but this has been remedied by cutting a slot between the electrodes at right angles to them, so that the path of discharge is opened to the air without the electrodes being uncovered. These arresters now show hardly any signs of use after seven or eight hundred discharges.

The manner in which the arresters are installed is a very important point, if they are to be of any service. The old way was to have an arrester on each line coming into the power house. When they failed to protect the dynamos, the blame fell on the construction of the arrester. The fact is, the arresters will not stop the lightning, but will, as I have said, gave it an opportunity to pass off. Choke coils should always be used in conjunction with spark gaps, and, when there are long stretches of line with no apparatus on them, it is sufficient protection to use a series of choke coils at each end, with spark gap arresters intervening. In the case of protecting transformers and other translating devices, they may be utilized as choke coils themselves.

The ground connection, above all, should be well made. It is usual to bury a copper plate or piece of iron casting in permanently damp earth, and the wire leading from it must be firmly soldered to it, and run as straight as possible. Most makers of arresters recommend that the ground plate be buried in broken charcoal. It is very important that the ground wire be straight, and not wound into any fancy coils, which increase its resistance, and may cause the current to leap off to some other object. I once noticed a peculiar thing in a power house which, I think, was caused by a bend in the ground wire. The arrester was placed on the back of the switch board, about two feet from the floor and three feet from the wall behind. The ground wire had to run under the floor to the wall, where it joined another wire which carried all the grounds to a copper plate buried in the earth. After a very strong discharge one night, a number of charred lines were to be seen on the floor, apparently running from the ground wire, as if the current had leaped from it.

PLANIMETERS

J. W. BAIN, '96.

The evaluation of the area of an irregular figure is a problem of frequent occurrence in certain departments of engineering, and it is because of the value of the planimeter in such determinations that this paper has been written.

The planimeter is an instrument for measuring areas, regardless of the character of the bounding perimeter. When we are dealing with simple geometrical figures, we can find the area, after a little calculation, from the measurement of certain lines; but when a figure whose boundary is an irregular curve comes under our notice resort must be had to the following process. A number of right lines are drawn to form triangles or rectangles, in such a manner that their combined area approximates, as closely as possible, to the true area of the figure. Simple and easy as this process is theoretically, in practice it becomes tedious, demanding the closest attention and considerable skill for the attainment of a moderate degree of accuracy. If only an approximate result is required, the planimeter may be used with great advantage, and both time and mental labor saved.

The first planimeter was probably invented by Hermann, of Munich, who worked it out with Læmmle, in 1814, and since then quite a large number of instruments have been designed on the same theory. Different though they may be in their mechanism, all these depend upon a certain principle, which may be enunciated as follows:

Let M (Fig. 1) be the plan of a disk rolling in contact with a straight guide PQ, which is parallel to OX, and at a distance from it equal to the radius of the disk, so that the plan of the centre of the latter always lies in OX. Let *m* be a roller upon the surface of the disk, graduated and connected with wheel-work and an index, so that the distance turned through over the surface of the disk can be read in revolutions, or parts of a revolution. The plan of the point of contact B of the roller with the

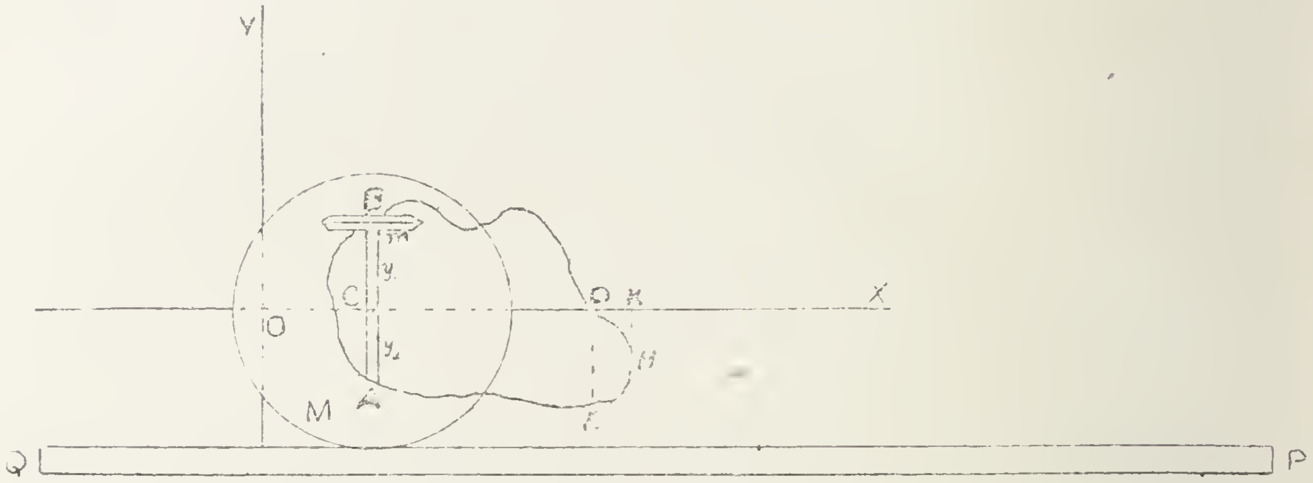

Fig. I

disk is always made to coincide with that particular point on the curve which is in a line, drawn at right angles, to OX, through the centre, C, of the disk. The plane of rotation of m, which may be called the measuring roller, is always perpendicular to the disk M, and the plan of its axis, as shown in the figure, is always parallel to OY, so that, in following the curve, it slips backwards and forwards across the surface of the disk in a direction parallel to OY.

It is important that the action of the measuring roller should be understood. Any motion may be resolved into two components: one in the plane of the roller, and the other parallel to its axis; and it is evident that the former will cause rolling, and the latter slipping, in the roller.

Suppose the disk to roll along PQ for a distance $\triangle x$ equal to the width of the element AB.

Then if y_1 = distance of B from OX,
R = radius of disk M,
r = radius of measuring roller m,
n_1 = consequent reading of measuring roller for this travel of disk.

Then $\frac{y_1}{R} \triangle x$ = linear distance turned through by a point on the disk at the distance y_1 from the centre.

$2\pi r n_1$ = linear distance turned through by a point on the circumference of m.

But since m rolls on M these distances are equal.

Therefore
$$2\pi r n_1 = \frac{y_1}{R} \triangle x$$

or,
$$n_1 = y_1 \triangle x \times \frac{1}{2\pi r R}$$

But $\frac{1}{2\pi r R}$ is a constant which, by taking r and R in suitable ratio, may be made unity.

Then $$n_1 = y_1 \triangle x$$

that is, the reading of the roller m measures that part of the area of the element above OX.

If the point of contact be made to follow round the curve continuously in one direction, then, when the portion of AB below OX is being measured, the disk is moving in the opposite direction along PQ; but, at the same time, the roller is turning in the opposite way, relatively to the disk, to that which it was doing before, since the point of contact is now below C. The final result of these two opposite motions is to cause the roller to turn as at first, and so add the result given for CA to what was given for CB. If the motion of disk $\triangle x$ for the width of AB be now regarded as negative, and $-y_2 =$ distance AC,

Also $n_2 =$ reading of roller for this element of area,

Then, by reasoning similar to that already used,

$$\begin{aligned} n_2 &= (-y_2)(\triangle x) \\ &= y_2 \triangle x \end{aligned}$$

Also $$n = n_1 + n_2 = (y_1 + y_2)\triangle x = y \triangle x$$
$$= \text{area of element AB.}$$

This reasoning holds for any possible position of the rollers or of the axis OX, which may be altogether outside the figure, as it is practically, for the integration of the portion DHE. Then it will be found that DKH is subtracted and DKHE is added, so as to give the required actual area DHE.

Inasmuch as this reasoning is independent of the actual value of the width of the element, and as the vertical motion of the roller m has no effect, in theory, upon the distance rolled through by it, therefore in limit, when $\triangle x$ becomes infinitely small, the actual value of the series of infinitely narrow strips which compose the figure ABDE is given by the final reading of the roller when the traverse of the boundary is completed.

This description, it is hoped, will enable the reader to understand the theory and action of the instruments of this class, which receive the general name of linear planimeters.

Passing on to the more important class of polar planimeters, we find that the first of any importance was invented by Prof. Amsler-Laffon, in 1856, and is known as the Amsler polar planimeter. This instrument is shown in Fig. 2, and consists of a radius bar a and a pole arm b jointed at C. The instrument is fixed at T by a needle point, on which is placed a weight W; the tracing point *p* is moved along the perimeter ABDE, and the roller *m*, which partly rolls and partly slips, gives the

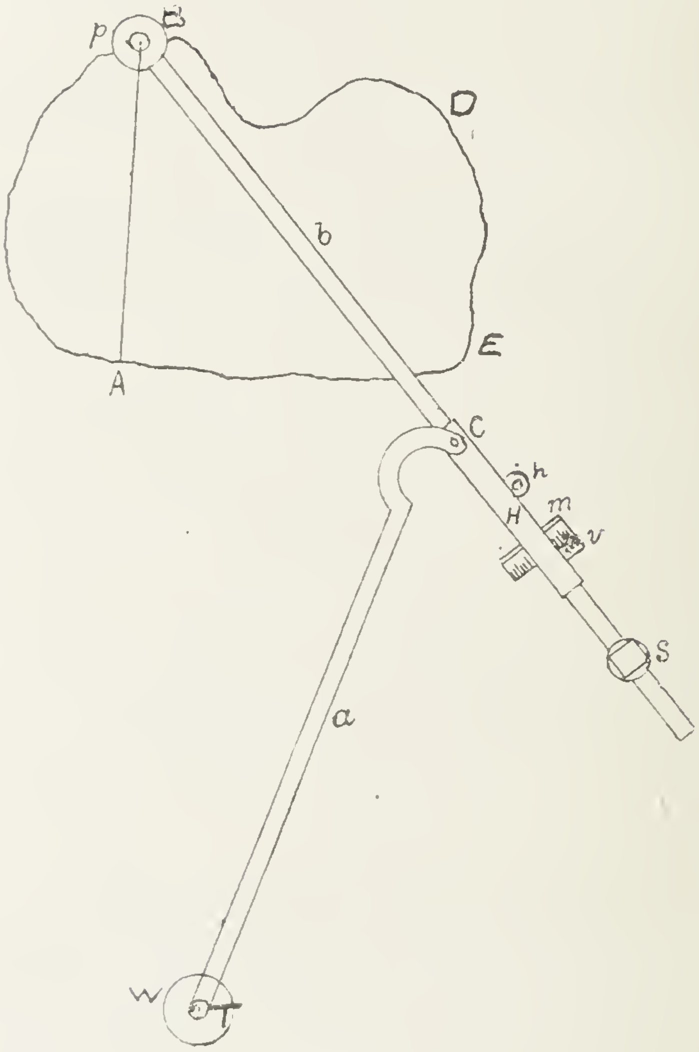

Fig. 2

area; by means of a dial *h* and a vernier *v* the result may be obtained to four places. The sleeve H can be placed in different positions along the pole arm *b* and fixed by a screw S, to give readings in different required units.

It is evident that when the plane of the wheel contains the point T the wheel *m* will not be turned as the pointer moves, since it is sliding in the direction of its axis; and the circle upon whose circumference the pointer moves under this condition is called the zero circle. The motion of the pointer *p* is made up of two motions, one the revolution of the radius bar *a* about the centre T, the other the revolution of the pole arm *b* about the centre C. In the latter motion, as the pointer *p* traverses the perimeter, the angle θ (Fig. 3) will have a series of values whose algebraic sum will be zero when the circuit is complete, or, in other words, the roller *m* will have made exactly as many revolutions in one direction as it has in the opposite direction. Hence this movement will have no effect upon the final record, and, theoretically, the arms a and b may be regarded as clamped firmly in one position.

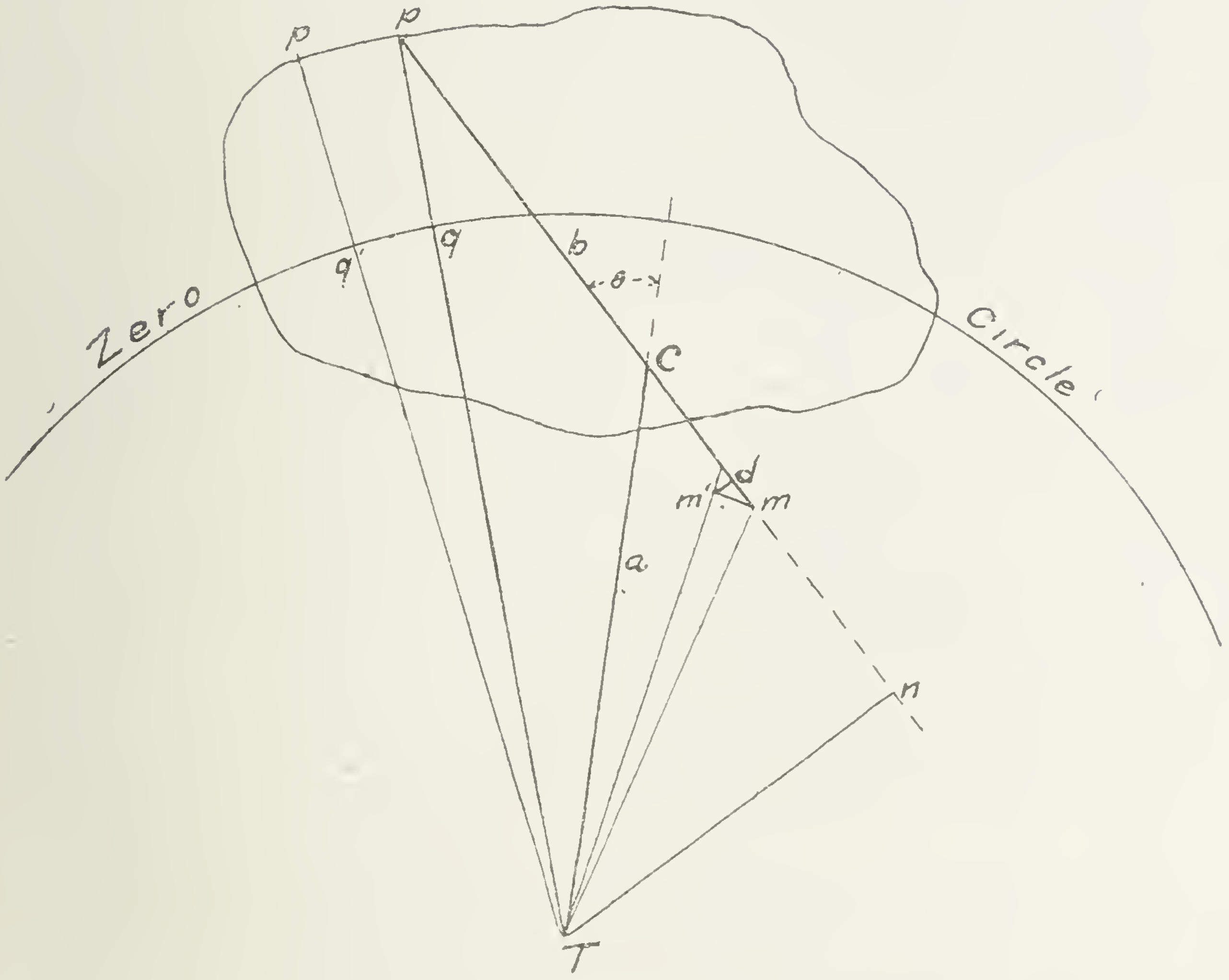

Fig. 3

Let the pointer traverse a small arc pp^1, which may be regarded as concentric with the zero circle, and let pp^1 subtend a small angle w at the centre T. Then the roller m will move along the path mm^1, which also subtends an angle w at the centre T. Drop perpendiculars m^1d and Tn from m^1 and T on pn. Let the angle T$\text{C}m = \theta$, $\text{CT} = a$, $\text{C}p = b$, $\text{C}m = c$,

Then the area $pp^1q^1q = \frac{1}{2}w\,(a^2 + b^2 + 2\ ab \cos\ \theta) - \frac{1}{2}\,w\,(a^2 + b^2 + 2\ cb) = wb\ (a \cos\theta - c)$, but b is a constant, and may be made equal to unity, hence area $pp^1q^1q = w\ (a \cos\ \theta - c)$.

Now, $mm^1 = m\text{T} \times w$ and m^1d, the record of the wheel is $= mm^1 \times \cos\ (\pi - \text{T}m\text{C}) = w \times m\text{T} \times \cos\ (\pi - \text{T}m\text{C})$. But $m\text{T} \times \cos\ (\pi - \text{T}m\text{C}) = mn = a \cos\theta - c \ \therefore m^1d = w(a \cos\theta - c)$.

Hence the wheel records the true area.

To show that proper summation is made on the wheel for the areas outside and inside the zero circle, Let A_0 = area generated by the line Tp, when the point p is outside the circle.

Let A_1 = area generated by the line Tp, when the point p is inside the circle.

Let S = area of sector between radii to points where the perimeter crosses the zero circle.

Let A = area of the figure.

Then $A_0 - S$ = outer area and $S - A_1$ = inner area.

The sum of these is $A = (A_0 - S) + (S - A_1) = A_0 - A_1$.

But since A_1 is recorded negatively on the wheel, while A_0 is recorded positively, the wheel record is $A_0 - (-A_1) = A_0 + A_1 = A$.

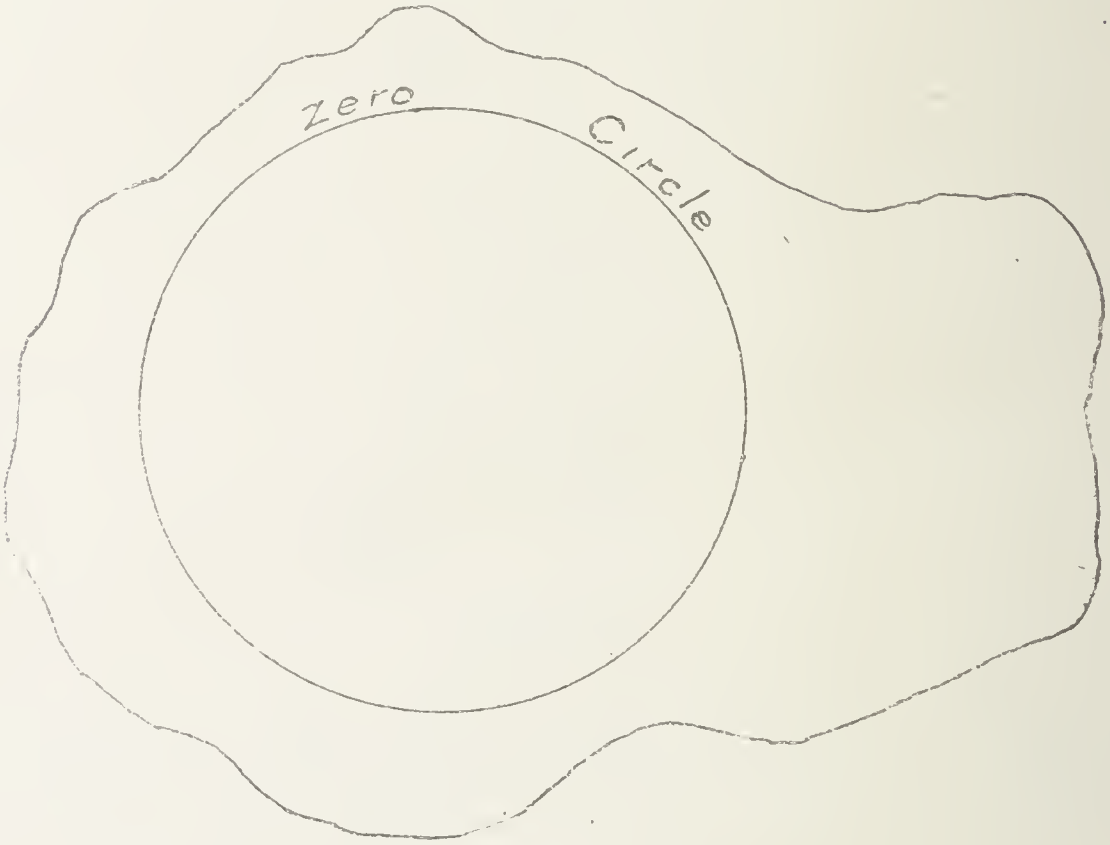

Fig. 4

We have until now discussed the case in which the point T falls without the figure, but, if we have a large area, we may be compelled to place the needle point T inside, as in Fig. 4. In the theory of the first case, the small area lying outside the zero circle was regarded as the difference between small sectors of the figure and of the zero circle; but in this latter case the sum of the sectors of the zero circle is equal to the area of that circle. Hence the record of the wheel is only the area lying between the zero circumference and the perimeter of the figures, and this leads us to an important rule. If the figure contains the needle point T, add the area of the zero circumference, which is π $(a^2 + b^2 + 2\,bc)$, to the wheel record.

In using the planimeter, the joints should be kept well oiled, the measuring wheel free from rust, and the whole instrument should be handled with care. When the sleeve has been adjusted on the pole arm for a certain unit, it is well to make a trial with a known area. If the value obtained be $\frac{1}{n}$th of the total area in error, the length of the pole arm may be changed in this ratio, or else the final result corrected in the same proportion. When practicable, it is best to have the needle point outside of the figure, since no correction is necessary. If it be placed inside, move the tracing point round the perimeter in the same direction as the hands of a watch. Then if the area be entirely within the zero circumference it will be negative, and since the area of the zero circle is positive the sum of the two will be the required area. Similarly, if the perimeter of the figure completely surrounds the zero circle, the area recorded will be positive, and will be added to the area of the circle. The value of b is known, and the values of a and c should be furnished by the maker. From these the area of the zero circle may be calculated according to the formula given above; or a given area may be measured with the middle point inside and outside, the difference of the two areas being the area of the zero circle.

Of other planimeters, depending on various principles, there is little to be said. Although more accurate than the two already described, they are very little used; in some cases only half a dozen instruments have ever been made. The two commonest, the suspended and the Coradi, are very accurate, but are also much more complicated in their mechanism and theory.

The planimeter may be applied in problems in surveying, in the calculation of earthworks, in the determination of horse power from indicator cards, and in many other ways which will occur to the reader.

For a comparatively complete treatment of the subject, "Mechanical Integrators," by Prof. S. H. Shaw, may be consulted; to him, and to Prof. J. B. Johnson, in his "Theory and Practice of Surveying," the writer is indebted for most of the theory given above.

Finally, in Williamson's "Integral Calculus," or in Minchin's "Uniplanar Kinematics," will be found solutions employing the calculus.

A BRIEF HISTORY OF ASTRONOMY

By W. L. Innes, C.E., O.L.S.

Astronomy is probably the most ancient of all sciences. Josephus assigns the founding of this science to the antediluvian patriarchs, although the honor is claimed respectively by the Chaldeans, Egyptians, Chinese, Indians, Gauls, and Peruvians.

According to the unanimous testimony of the Greek historians, the earliest traces of the science are to be found among the Chaldeans and Egyptians. Both the pastoral life of the people, the clear atmosphere and level country of Chaldea, were very favorable for the study of astronomy.

After a long series of observations of eclipses, the Chaldeans discovered the period Saros, a cycle of 223 lunations, or eighteen solar years, which brings back the moon to nearly the same position with respect to her nodes, perigee and the sun bringing back the eclipse in the same order. This enabled them to predict all eclipses included in the cycle, but involved neither theory nor science.

The ancient Egyptians rivalled the Chaldeans in the cultivation of astronomy, but have left very few traces behind them. The Greeks, acknowledging themselves indebted to the Egyptians for their science and civilization, have greatly exaggerated their advancement in this respect, placing them even ahead of the Chaldeans.

The Phœnicians, who certainly excelled at navigation, are also mentioned among the ancient nations who studied astronomy. It is not improbable that in their long voyages they would make use of the circumpolar stars, but their knowledge of astronomy was probably derived from the Chaldeans or Egyptians.

It would almost appear that the Chinese were the first to cultivate astronomy. Certainly, from the remotest ages, this science has been considered as inseparable from administration of the civil government.

The arrangement of the calendar induced the Chinese, as also the

Chaldeans and Egyptians, to study the motions of the heavenly bodies, and it is the boast of this exclusive people that the national record of eclipses extends over a period of 3858 years. Not only this, but that these eclipses were all previously calculated, as well as carefully observed.

The Emperor Fou-Hi, B.C. 2857, is said to have studied astronomy, and attempted to instruct his subjects in the science, but, due to their ignorance, he was obliged to content himself with giving them a rule for calculating time, by the combination of the numbers 10 and 12, which produces a cycle of sixty years—the standard from which they deduce the hours, days, and months.

B.C. 2608, Hoong-Ti built an observatory for the purpose of connecting the calendar, and appointed three sets of astronomers to observe the sun, moon, and stars respectively. They discovered that the twelve lunar months did not correspond exactly with a solar year, and that an intercalation of seven lunations in the space of nineteen years was required to restore the coincidence. From this it would appear that the Chinese discovered the metonic cycle two thousand years previous to the Greeks. It was in this reign that the mathematical tribunal was established for promoting astronomy and predicting eclipses, to which great importance has always been attached. Probably great honor was attached to a membership in this elaborate tribunal, though attended with considerable danger, as it was enacted that "whether the instant of the occurrence of any celestial phenomenon was erroneously assigned, or the phenomenon itself not foreseen and predicted, either negligence should be punished with death"—law to which two of the mathematicians of the empire subsequently fell victims.

From the time of Yao, B.C. 2317, the Chinese year consisted of 365¼ days. The exact value is 365.24222 days—certainly a remarkably close approximation, differing only by about eleven minutes. They also divided the circle into 365¼ degrees.

Another much more remarkable instance of a measurement of precision is to be found in the annals of Chinese astronomical history. In the reign of Tcheou-Kong, which commenced B.C. 1100, the obliquity of the ecliptic was found to be $23° 54' 3.15''$—a result which agrees perfectly with the theory of universal gravitation. It may be here remarked that from more recent observations upon the obliquity, it is found to be diminishing. At the present time its rate of decrease amounts to about $45\frac{1}{2}''$ per century, which may be regarded as uniform for many centuries to come. This decrease will continue until it reaches the maximum of about 3°, after which it will slowly increase until it reaches the same maximum on the other side of the mean value.

About the same time the position of the winter solstice in the heavens was determined, and it corresponds to within a minute of a degree with the calculations of Laplace about A.D. 1775. This extraordinary conformity was considered by Laplace as an undoubted proof of the authenticity of their ancient observations.

It is unfortunate that the history of China prior to B.C. 722 is not very reliable. However, between that period and B.C. 400, Confucius reckons a series of thirty-six eclipses, thirty-one of which have been verified by modern astronomers. After this the decline of Chinese astronomy took place, due, it is said, to the barbarous policy of one of their emperors, who ordered all the books to be destroyed B.C. 221.

It will be observed that the early Chinese astronomy—outside of the practice of observations, which led to very little—amounted to nothing theoretically.

Fables are in existence showing the methods employed by the ancient inhabitants of India to predict eclipses and the position of planets, and indicating a high state of civilization. However, the difficulty arises in assigning the data of these and their origin. Some consider India as the cradle of all sciences, particularly that of astronomy; others think it was carried thither from Greece at the time Pythagoras travelled into that country; others, again, consider it was obtained from the Arabians in the ninth century of our era.

The Ionian school of science was founded in Greece, by Thalese, B.C. 640. He taught that the earth was the centre of the universe, was spherical, and divided it into five zones, by the Arctic and Antarctic circles and the two tropics. He also taught that the moon received its light from the sun, and that the stars were formed of fire.

Thalese was succeeded by Anaximander, who invented the gnomon or sun-dial, and with it observed the solstices and equinoxes. His greatest note is derived from inventing the geographic chart.

The succeeding leaders of this school appear to have added nothing of importance to the principles already taught.

While the Ionian sect was successfully employed in cultivating and propagating a knowledge of nature in Greece, another, still more celebrated, was founded in Italy by Pythagoras, who is said to have acquired, in Egypt, a knowledge of the obliquity of the ecliptic and the identity of the morning and evening stars.

He taught publicly that the earth was the centre of the planetary world, though, to his disciples, he taught that the earth and planets revolved round the sun.

Philolaus followed in this school. He supposed the son to be a disk of glass which reflected the light of the universe. He made the lunar month consist of 29½ days; the lunar year, 354 days; and the solar year, 365½ days.

Cicero credits Nicetas, the next leader of this school, with having maintained that the apparent motion of the stars arises from the diurnal motion of the earth about its axis.

The difficulty of reconciling the motions of the moon and sun was first overcome (at least, for a time) by the introduction of the metonic cycle, July 16th, 433 B.C., by Meton. It consisted of 125 full and 110 deficient months, which gives 6,940 days for the 235 lunations, and is nearly equal to 19 solar years. A deficient month consisted of 29 days, and a full month 30 days.

As already noted, it is not improbable that the Chinese discovered this cycle some two thousand years before.

About 370 B.C., Euduxus introduced the year of 365¼ days into Greece. He supposed the diameter of the sun to be nine times greater than that of the moon. He is noteworthy for having contempt for the Chaldean predictions, and contributing towards separating true astronomy from astrology. He supposed each planet occupied a particular part of the heavens, and that the path which it discovered is determined by the combined motions of several spheres performed in different directions. The sun and moon had each three spheres, one revolving round an axis which passed through the poles of the earth, and which occasions the diurnal motion; a second revolving round the poles of the ecliptic in a contrary direction, causing the annual and monthly revolutions; the third revolving in a direction perpendicular to the first, and causing the change in declination. Each of the planets had a fourth sphere, and, as new inequalities and motions were discovered, new spheres were added, until the machine became too complicated to be intelligible.

Eudemna was the first Greek to assign a rate to the obliquity of the ecliptic. His value was the side of a pentedecagon, or 24°.

ALEXANDRIAN SCHOOL.

Rythias, of Marseilles, about the time of Alexander the Great, determined the length of the solsticial shadow, in various countries, by means of the gnomon. The observation is interesting, as it confirms the successive diminution of the obliquity of the ecliptic. He was also the first who distinguished the climates by the different lengths of day and night.

Aristillies and Timocharis, B.C. 300, determined the positions of the principal stars of the zodiac, and this led to the important discovery of the procession of the equinoxes.

Aristarchus, the next of the Alexandrian astronomers, in his book, which has been preserved till to-day, describes an interesting method of determining the relative distance of the sun and moon. When precisely half the disk of the moon was illuminated, he measured the angle between it and the sun to be 87°, and concluded the sun to be between 18 and 19 times more distant than the moon. The theory of his method is perfectly correct, but the practical application very imperfect, on account of the difficulty to determine the exact instant when the half of the moon is illuminated. The true angle is about 87°50′, and the true mean distance of the sun 383 times that of the moon. However inaccurate the measurement was, it served to greatly expand the ideas of the times, as the prevailing opinion was that the sun was only about three times more distant than the moon.

Another delicate and difficult observation, made by Aristarchus, was that of the sun's diameter. He determined it to be the 720th of the circumference of an inch, or thirty minutes, which is very near the truth.

Eratosthenes succeeded Aristarchus, and determined the obliquity of the ecliptic to be 23° 51′ 19.5″. This a very important observation, and confirms the gradual diminution of the obliquity, as indicated by theory.

This man is celebrated for having made the first attempt, on correct principles, to determine the magnitude of the earth. Syene was known to be on the same meridian as Alexandria, also exactly under the tropic; for at the summer solstice the gnomon, or sun-dial, had no shadow, and the rays of the sun illuminated the bottom of a deep wall in that city. On the day of the solstice he measured the zenith distance of the sun at Alexandria to be 7° 12′, a fiftieth part of the circumference. The distance from Alexandria to Syene was 5,000 stadia; therefore, the circumference of a great circle of the earth was 250,000 stadia, but, unfortunately, we cannot judge the accuracy of this rude determination of the sign of the earth, as the length of the stadia is unknown.

Astronomy, till the time of Hipparchus, who observed at Rhodes, consisted only of a knowledge of isolated facts. He reduced it to a system, commencing his brilliant career by verifying the determination of the obliquity of the ecliptic made by Eratosthenes.

He next determined the length of the tropical year to be 365 days, 5 hours, and 49 minutes, which is only twelve seconds greater than the truth.

By a careful observation of the solstices and equinoxes he discovered that the year is not divided at these points into four equal parts, the sun occupying 94½ days in passing from the vernal equinox to the summer solstice, and only 92½ from this point to the autumnal equinox. The sun, therefore, remains 187 days north of the equator, and only about 178 days south of it. This led Hipparchus to the great discovery of the eccentricity of the solar orbit. The discovery of the eccentricity led him to that of the inequality of the length of the solar day at different seasons of the year. The sun advances by his own proper motion to the east about one degree between two successive meridian transits, but the rate of motion is unequal, varying between fifty-seven and sixty-one minutes of a degree.

Hipparchus next directed his attention to the moon. From the comparison of a great number of the recorded eclipses by the Chaldeans, he determined the period of the moon's revolution relative to the stars, the sun, her nodes, and her apogee. These determinations are among the most valuable results of ancient astronomy, inasmuch as they corroborate the acceleration of the mean lunar motion, and thus form one of the most delicate tests of the truth of Newton's law of gravitation.

Hipparchus also determined the eccentricity of the lunar orbit, and its inclination to the plane of the ecliptic. His values, after making due allowance for slight changes which are taking place, correspond closely with modern observations. He approximated to the parallax of the moon, and concluded that the greatest and least distance of the moon are, respectively, 78 and 67 semi-diameters of the earth ; also that the distance of the sun is 1,300 semi-diameters. The first determination exceeds the truth, but the second falls greatly short of it, being about one-half the true distance.

He catalogued 1,080 stars visible above his horizon, and was rewarded for his trouble by discovering the procession of the equinoxes, one of the fundamental elements of astronomy.

A comparison between his own observations and those of Aristillies and Timocharis, about 150 years before, showed that the first point of Aries had advanced two degrees, or at the rate of 48 seconds a year. Modern observations give the rate at 50.1 seconds annually.

He invented the planesphere, a method of representing the heavens on a plane surface.

He was the first who demonstrated the solution of rectilineal and spherical triangles, and constructed a table of chords, from which he derived nearly the same advantage as we do at present from a table of sines.

He also was the first to fix the position of planes on the earth's surface by means of their latitude and longitude, as well as the first to use the eclipses of the moon as a means of determining longitude.

Some three centuries elapsed after the death of Hipparchus before Ptolemy, A.D. 130, the first successor in the Alexandrian school worthy of the name, appeared.

He is particularly distinguished for having collected and arranged the ancient observations, although he is entitled to a high place among astronomers on account of his own discoveries. The most important is the evection of the moon. Hipparchus had discovered the first lunar inequality, and undertook a set of observations to determine its amount and law, but death put a stop to his labors, which were completed by Ptolemy, who discovered that the eccentricity of the lunar orbit is itself subject to an annual variation, depending on the motion of the line of apsides. The variation of the position of the apsides produced an inequality of the moon's motion in her quarters, which has been called the evection.

Ptolemy employed a very simple process for determining the moon's parallax. First, he found the latitude of a place a little south of Alexandria when he observed over the zenith of which the moon was found to pass when her north declination was the greatest possible. In this position the moon, observer, and centre of the earth are in the same straight line, and, consequently, she has no parallax. The obliquity of the ecliptic and the latitude of the place being known, the moon's greatest northern latitude was also determined. Second, he observed the moon's meridian altitude fifteen days subsequent to the first observation, when her southern latitude was necessarily the greatest possible. This observation gave the apparent altitude of the moon ; but the greatest northern and southern declinations being supposed equal, her true altitude, as seen from the centre of the earth, was easily computed from the previous observation, and the difference between the true and apparent altitude gave the amount of the parallax.

Ptolemy confirmed the observations of Hipparchus relative to the motion of the stars in longitude, but diminished a quantity which Hipparchus had already estimated too low.

He is called the prince of astronomers, a title which may be given him from the universal and long-continued prevalence of his system, but to which he has no claim from the number or value of his own observations. A great deal, at least, of the information he has left behind is supposed to be computed from the tables of Hipparchus.

Albategni, born A.D. 850, appears to have been the next great astronomer. He was an Arabian, a Syrian prince, and resided at Kakka, in Mesopotamia, but many of his observations were made at Antioch.

He forms the link between the astronomers of Alexandria and of modern Europe. Having studied the methods practised by Ptolemy and the Greek astronomers, he began to observe, and soon found the places of many of the stars given in Ptolemy's tables to be considerably different from the actual situations.

He measured the rate of procession with greater accuracy than had been done before, and determined the eccentricity of the solar orbit. His value for the latter differs very little from modern observations. In determining the length of the year he made an error of more than two minutes.

He noticed that the sun's apogee advanced at a slow rate, and constructed a set of astronomical tables more accurate than those of Ptolemy.

Ibu-Junis, who lived in the beginning of the eleventh century, constructed a set of tables, and composed a history, in which he recorded numerous observations of his own and other astronomers of the same country. This work was translated in 1804, and contains twenty-eight observations of eclipses between 829 and 1004; seven of the equinoxes; one of the summer solstice; one of the obliquity of the ecliptic made at Damascus, which gave it to be 23° 35′; and likewise a portion of tables of the sun and moon, with other information.

In 977, 978, and 979 Ibu-Junis observed two eclipses of the sun and one of the moon near Cairo, which agree with theory in confirming the existence of an acceleration of the mean lunar motion.

A Tartar prince, Ulugh Begh, established at Samarcand, the capital of his dominions, an academy of astronomers, and furnished for their use the most magnificent instruments. By means of a sun-dial 180 feet high he determined the obliquity of the ecliptic to be 23° 30′ 20″, the procession of the equinoxes 1° in seventy years, and formed elements for constructing tables equal in accuracy to those of Tycho Brahe.

Hipparchus had the honor of constructing the first star table, but Ulugh Begh that of the second, after an interval of sixteen centuries. His death ended the last great astronomer of the East.

REVIVAL OF ASTRONOMY IN EUROPE.

During the life of George Purbach, born 1423, astronomy in Europe again began to flourish after a long standstill of ages. He became noted as a professor, and, though ignorant of both Greek and Arabic, translated, through his perfect acquaintance with the subject, Ptolemy's Almagest, correcting many errors in former translations. He found a disciple, John Muller, who executed many of the plans interrupted by his premature death.

John Muller, better known as Regiomontanus, studied under Purbach in Vienna for ten years, and after his master's death he moved to Rome, and translated into the Latin the works of Ptolemy and other treatises of ancient science. In 1471 he retired to Nuremberg, when, with the aid of a wealthy burgess, Bernard Walther, he founded an observatory, and equipped it with instruments principally of his own design, by means of which he detected many inaccuracies in the ancient tables. Walther continued to observe after the death of Regiomontanus for thirty years. His observations were collected and published for the first time in 1544. He introduced the use of clocks to measure time in celestial observations, and was the first to employ the planet Venus to determine the longitude of the stars.

We now arrive at the overthrow of the Ptolemaic system, and total renovation of the science of astronomy by Copernicus. His system simply supposed the heavens composed of stars perfectly at rest, occupying the remotest bounds of space, then the orbit of Saturn, next Jupiter, Mars, the Earth (accompanied by its moon), Venus, Mercury, and, lastly, the sun immovable at its centre. By this arrangement, the stations and retrogradations of the planets became simple mathematical corollaries,following from the difference of the radii of the orbits and the unequal motions. The diurnal motion of the earth explained more simply and rationally the apparent daily revolution of the heavens, and the procession of the equinoxes was referred to a small variation in the inclination of the earth's axis to the plane of the ecliptic. However, the simplicity of the system, and its consequent probability, was the only proof Copernicus could advance to substantiate its reality.

The subsequent discovery by Richer of the diminution of gravity towards the equator left no further room for doubt as to the earth's rotary motion. The measurement of the velocity of light by Roemer, and the phenomena of aberration observed by Bradley, also reduced to a certainty its annual revolution. Copernicus, after the example of the ancients, assumed the uniform circular motion of the planets, and to explain the observed variations he was obliged to suppose different centres for each orbit. The sun was placed inside them all, though at the centre of none, and, consequently, had nothing else to do but supply the planets with light and heat; being excluded from any influence on the system, he became a stranger to all the motions.

Tyco Brahe is the next in order who contributed to the progress of astronomy. He is justly considered far superior to any of his predecessors (since the revival of astronomy in Europe) as an indefatigable and skilful observer.

He constructed the first table of refractions, and his solar tables were extremely accurate. He greatly improved the lunar tables, and detected inequalities in the moon's motion in longitude, which he named variation, and by which it still continues to be distinguished. He discovered an equation in latitude similar to evection, and fixed its amount accurately. He showed that the region of comets was far beyond the orbit of the moon, and determined the relation and absolute position of 777 stars with scrupulous exactness.

Tyco Brahe left a regular series of observations of the planets, which Kepler, his disciple, made use of to establish the system of Copernicus. Kepler may be said to have constructed the edifice of the universe from the material supplied by Tyco.

For some twenty long years Kepler labored under a mistaken idea that the ancients had not disputed, and which Tyco Brahe had accepted, namely, that the planets move in circles; but having computed with incredible labor the observations of seven oppositions of the planet Mars, he discovered that the motions could only be accurately represented by supposing it to move in an ellipse, having the sun in one of its focii.

He next proceeded to consider the angular motions of the planets, and concluded that the universally accepted uniform motion did not exist in nature. He perceived, however, that in equal times the radius vector described equal areas, and eventually extended this to include all planets.

It was some years later before he made what he considered the most important discovery. He found that the squares of the periodic times of the planets are always in the same proportion as the cubes of their mean distances from the sun. He showed it to be true of all the planets then known, and it has been found equally true in regard to those since discovered, and also to prevail in the systems of the satellites of Jupiter and Saturn. Indeed it is a necessary consequence of the law of gravitation.

The three laws known by Kepler's name are:

(1) Each planet moves around the sun in an ellipse, having the sun in one of its focii.

(2) The radius vector joining each planet with the sun moves over equal areas in equal times.

(3) The square of the time of revolution of each planet is proportional to the cube of its mean distance from the sun.

These brilliant discoveries reduced the solar system to that beautiful simplicity conceived by Copernicus, but from which he found it necessary to depart.

Kepler was the first to make a practical use of eclipses, by using one of the sun to determine a difference of meridians.

He promptly embraced the new invention by Lord Napier, of Scotland, of logarithms, and constructed a table from which the logarithms of the natural numbers, sines, and tangents could be taken at once. It may be here mentioned that without this or some other similar process the computations rendered necessary by more correct observations could not be made, and astronomy could not have acquired that precision and accuracy by which it is now distinguished. He passed some sound and accurate notions of the nature of gravity, but, unfortunately, conceived it to diminish simply in proportion to the distance, although he had shown the intensity of light to vary inversely as the square of the distance from the luminous body.

Contemporary with Kepler was the celebrated Galileo. While residing at Venice he heard it reported that a Dutch optician, Metius, had discovered a combination of lenses by means of which distant objects appeared nearer. This aroused his curiosity, and he immediately enquired into the reason. His researches were attended with prompt success. On the following day he had a telescope that magnified three times. His second telescope magnified about seven or eight times, and he was subsequently enabled to increase the magnifying power to thirty-two times.

Through his telescope he perceived numerous inequalities in the surface of the moon, from which he concluded, almost with certainty, that it was an opaque body reflecting the light of the sun. The planet Venus exhibited similar phases. He detected the four moons of Jupiter and spots on the sun, from which he deducted the rotation of that body on its axis in the space of twenty-seven days.

Science is indebted to Galileo for two still more important discoveries, namely, vibrations of the pendulum in equal times and the law of acceleration of falling bodies.

Horrox and his friend Crabtree were the first to observe, on the 24th of November, 1639, that rare phenomenon, a transit of Venus over the sun's disk.

Huyghens improved the telescope and introduced the pendulum to clocks. He discovered that the peculiar appearance of Saturn was due to a ring surrounding the body of the planet.

Picard, in 1667, applied to the telescopes cross wires in the focii, and micrometers to graduated instruments, and was thus enabled to observe the stars in the daytime.

Roemer, the friend and pupil of Picard, discovered the progressive motion of light in 1675, and measured its velocity by means of the eclipses of Jupiter's satellites, and was the first to erect a transit instrument.

The Royal Observatory of Paris was completed in 1670, and Dominic Cassini entrusted with its direction. He determined the motions of Jupiter's satellites from observations of the eclipses. He observed that Saturn's ring is double, and discovered four satellites of that planet. He also determined the rotation of Jupiter and Mars, and made a number of observations on Venus with the same view. He made a near approximation to the parallax of the sun, and was the first to calculate tables of refraction on correct principles. He left a complete theory of the vibration, or balancing, of the moon.

Newton discovered three laws of motion, which are:

(1) Every body preserves its state of rest, or of uniform motion, in a right line, unless it is compelled to change that state by forces impressed thereon.

(2) The alteration of motion is ever proportional to the moving force impressed, and is made in the direction of the right line in which that force acts.

(3) To every action there is always opposed an equal reaction; or the mutual actions of two bodies on each other are always equal, and in opposite directions.

Peterborough, October 15th, 1895.

STANDARDS IN MACHINE SHOP PRACTICE

H. V. Haight, '96.

The present is, to a great extent, an age of standards. In every department of business, and of life, the tendency is to fix certain standards by which things shall be judged, measured, or valued, or to which, within certain limits, all similar things must conform. As this tendency is nowhere more evident than in the work in which we, as engineers, will soon be engaged, and, as the subject is of great importance, it becomes our duty, as engineers, to get acquainted with the present condition of affairs in this line. The subject is much too extensive to permit us to consider, even briefly, the great number of standards in connection with machine shop practice. About the best we can do is to describe the ultimate standards, and some of the more important and interesting practical standards.

ULTIMATE STANDARDS.

The ultimate standards, in scientific work, are those of length, mass, and time. From these we derive our standard units in light, heat, sound, electricity, mechanics, etc. In what is called the absolute, or C.G.S. system, for instance, the units of length, mass, and time are the centimetre, gram, and second. The unit of force, in this system, is defined to be that force which, acting on a gram of matter for one second, will produce in it a velocity of one centimetre per second. Similarly we may express other physical quantities in terms of length, mass, and time.

In the machine shop we are chiefly concerned with the standards of length. In whatever line we may attempt to establish a standard we are confronted with the problem of the ultimate standard of length. A standard screw thread, for instance, consists in a standard shape and standard dimensions. The shape may be defined without reference to any standard of length, but in order to describe the size we have to bring in the term inch, or millimetre, or some similar term. The question then arises, what is an inch, or, what is a millimetre?

You may think this a very simple question, and say that every one knows what an inch means. But take a couple of foot rules, a steel machinist's scale, and a boxwood engineer's scale, for instance, and compare their lengths. You will find that a difference between the two of one-twentieth of an inch in the foot is not uncommon. And if you were to put one of those scales in a comparator and measure the successive inches, you would find that no two of them were the same length. It is clear, then, that we must have some ultimate standard to which we can refer.

The chief considerations for a standard of length are that it shall be *definite*, *easily copied*, and *unchangeable*. It would be an advantage if we had some natural standard which would fulfil these conditions; but, so far, no satisfactory one has been found. Nearly all, if not all, of our standards of length were originally derived from some natural unit. These standards were mostly personal. We have, for instance, the digit or finger's breadth, the palm or hand's breadth, the span, the foot, the step, the double step or pace, the cubit or distance from the elbow to the extremity of the middle finger, the fathom, or greatest extension of the outstretched arms, and the gird, or yard, the distance around the girdle. In England there have been such *legalized* standards as the length of the arm of King Henry I., and the foot made up of "thirty-six barley-corns, round and dry, placed end to end." It is evident that none of these natural units fulfil the first and most essential condition of a standard—that of being definite. They were, without doubt, suited to the primitive times in which they were employed. Their chief use was in trade and commerce, where the fluctuations in prices were so great that a difference in the size of the measure was comparatively unimportant.

Various attempts have been made to establish a unit of measurement based upon an unchangeable natural unit. Many eminent philosophers, such as Huyghens in 1670, Picard in 1781, and Talleyrand in 1790, have proposed the length of the seconds pendulum. Other natural lengths proposed as standards were based upon the dimensions of the earth. Cassini, in 1718, proposed the $\frac{1}{6000}$ of a minute of a degree of a great circle, which would be nearly equal to a foot. The three units proposed to the Assembly of France as the basis of what is now known as the metric system were the length of the seconds pendulum, the ten-millionth part of a quarter of the equator, and the ten-millionth part of a quadrant of a meridian. The International Commission adopted the latter. More recently still another natural unit has been proposed. This is the wave length of monochromatic light.

These three bases of measurement, the length of the seconds pendulum, the dimensions of the earth, and the wave length of light, are believed to possess the necessary properties of being definite and unchangeable (though there is some doubt of the latter); but they are not easily copied. The earth seems too large, the wave length of light too small, and the length of the pendulum too difficult of accurate determination, to be used as an ultimate standard. We are thus forced to fall back on an arbitrary standard established by law.

THE YARD.

There are at present two chief standards of length, the British Imperial yard and the French Mètre des Archives. The yard is the standard of length in Great Britain and her colonies, and in the United States. In Russia the standard foot is the same length as the English foot; so that the foot is about the most largely used standard of length in the world. The present British standard yard is a solid square bar of Baily's metal, kept in the office of the Exchequer at Westminster. It is thirty-eight inches long and one inch square, and is composed of copper, 16 parts; tin, 2½ parts; zinc, 1 part. Near each end of the bar a hole is drilled partly through it, and in these holes gold plugs are inserted, whose polished surfaces are level with the axis of the bar. Across each plug is marked a fine line. The distance, at 62° Fah., between these lines constitutes the Imperial yard.

This standard was made legal in 1855. It was constructed to replace the old standard which was made by Bird in 1760, became the legal standard in 1824, and was destroyed at the burning of the Parliament buildings in 1834. After the destruction of the old standard an attempt was made to replace it from a measurement of the length of the seconds pendulum, the Act legalizing the old standard having made provision for its restoration by that means, if at any time it were injured or destroyed. But "it has been proved conclusively since the passage of the Act (legalizing the old standard) that there were errors in the determination of the specific gravity of the pendulum employed; the reduction to the sea level had been shown, by Dr. Young, to have been doubtful; the reduction for the weight of air was also proved erroneous; and Kater showed that sensible errors had been introduced in comparing the length of the pendulum with Shuckburgh's scale."*

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* "Standards of Length and their Practical Application." Published by Pratt & Whitney.

The attempt to restore the lost standard by reference to the pendulum was therefore abandoned, and it was finally replaced by the use of standards then in existence which had been compared with the original yard.

To guard against a repetition of this calamity, four parliamentary copies of the new standard were constructed. These are kept at different places in London. There were also forty other copies of the new standard made for distribution among the different governments. Only two of these are exactly standard at 62° Fah., and these are kept at the Royal Observatory. All of the others have a certain relation to Bronze 1, as the new standard is called, and, instead of giving their errors, the temperatures at which they are standard is given. Bronze 11 is in the possession of the United States, and is kept at the office of the Coast Survey, at Washington. When it was presented to the United States in 1856 it was stated to be standard at 61°.79 Fah., but comparisons made in 1878 have shown that it is eighty-eight millionths of an inch *shorter* than Bronze No. 1 at 62° Fah., and that it must therefore be considered standard at 62°.25 Fah.

THE METRE.

The other important standard referred to is the Mètre des Archives, the ultimate standard of the metric system of weights and measures. This great system, used now in more countries than any other system, and apparently destined to become universal, had its origin in France. Toward the end of the eighteenth century the greatest confusion existed in the weights and measures used in France. It is said that there were as many as a hundred different measures of area alone. Instead of attempting to reorganize the system, as was done in many other countries when their measures got confused, as the English measures were reorganized in 1824, for instance, the French determined to originate a new system for universal use. In 1790 the French Government asked the British Government to co-operate with them in establishing a uniform international system of metrology. The British Government rejected the proposal, but other governments were not so conservative, or else their measures were in a worse state than those of Great Britain, for the International Commission which met to consider the matter had representatives from Holland, Spain, Savoy, Tuscany, etc. The commission adopted the standard which had been proposed by Laplace and Lagrange, with the support of the principal mathematicians of that period, namely, that the unit of linear measurement should be the ten-millionth part of the earth's quadrant, the length to be determined by the measurement of an arc of 9° 40′ 24″, between Dunkirk and Barcelona. A trigonometrical measurement of the distance was accordingly made, Delambre having charge of the work for part of the distance, and Mechain for the other part. From the results of this measurement the length of the metre was deduced, and the Mètre des Archives constructed. This is an end measure standard, made of an alloy of platinum and iridium, containing 10 per cent. of the latter metal, and is standard at O°C. It has since been shown that there were errors in this work. In the report of the United States Coast Survey, the length of the quadrant of a meridian passing through Paris is given as 10,001,472.5 metres, which is probably very nearly correct. This makes the difference between the actual length of the metre and the intended length about fifteen-hundredths of a millimetre, or six-thousandths of an inch.

After all attempts to make the Mètre des Archives conform to some natural unit were abandoned, it was finally made the legal standard. In this respect, therefore, it is no better than the British yard. The decimal feature, however, and the practical identity of the litre and the cubic decimetre and of their volume in water with the kilogram, make the metric system of the greatest value. Scientists have been practically driven to use it for these reasons.

The metric system has been gradually making its way ever since its origin. The metre is now the standard of measurement in France and her colonies, Italy, Germany, Portugal, Norway, Sweden, Greece, Bulgaria, Roumania, Mexico, Brazil, Peru, New Granada, Uruguay, Chili, Venezuela, Argentine Confederation, and Japan, and it is practically the standard in British India, Austria, Bavaria, Wurtemburg, Baden, Hesse, Denmark, Turkey, and Switzerland. The metric system is legal in the United States, is used in the State of Utah, and its use is permissive in England, Canada, and Russia. It is coming into use for pharmaceutical and medical purposes, and will be used in the new edition of the British Pharmacopœia.

A great effort has been made this last year to have it made the legal standard in Great Britain. An interesting account of this is given in *Nature* of November 28th, 1895.

THE VALUE OF STANDARDS.

The great need of such accurately defined standards of length in shop work is in the making of interchangeable parts of machinery. The old method of manufacture was what might be called the individual method.

Each part of the machine was fitted into the place in which it belonged. This made it necessary for the one manufacturer to make the whole machine. The more modern method, applicable whenever a large number of machines, or parts, of the same kind are to be made, is to make the parts to standard dimensions by using standard gauges and tools. Then parts can be taken from each lot indiscriminately, and be put together to form the finished product.

Often, in fact, different parts of the machine are made by different manufacturers, and in different places. Now, in order that these parts shall fit one another, it is necessary that the different manufacturers should have a common standard. For instance, an inch should mean the same thing to the manufacturer of taps in Hartford that it does to the manufacturer of screws in Hamilton.

The chief advantages of this system of manufacture are as follows:

(1) *Lessened Cost of Production.*—It will be easily understood that a single detail of a machine, receiving the whole attention and application and capital of a manufacturer, and being produced in immense quantities, can be made more cheaply than the manufacturer of the machine could make that detail himself. Again, that time is saved which would be spent in fitting each piece to its place, in marking it, and in keeping it separate from similar pieces.

(2) *Facility of Repairs.*—A new part may be made at any time without reference to the machine or part which it is to fit. Parts may be kept on hand, so that very little time will be lost if anything breaks. Facility of repairs is especially necessary in railroad work, and the making of parts to standard form and dimensions becomes especially valuable.

The standard system of measurement and the interchangeability of parts is a necessity in our present system of manufacture. The first great application of this method was that made by Eli Whitney in applying it to the manufacture of small arms for the United States Government. In 1822 the Secretary of War admitted to Mr. Whitney that they were saving $25,000 a year, at the two public armories alone, by the use of his improvements. In later years the introduction of typewriting, typesetting, and cash registering machines, which required to be made in large quantities and sold at a low price, rapidly brought this system of manufacture into use. Another factor which has aided in the introduction of this system among workingmen in general is the perfection and low cost of small micrometer calipers. At present, parts of machines measure and are regularly duplicated in ten-thousandths of an inch. Very fine work is made even more accurate than this. As measuring tools, gauges, etc., must be more accurate than the finest work for which they are to be used, it will be seen that, in standard gauges, a very high degree of accuracy is necessary. Manufacturers of end measure pieces, for instance, guarantee them to be accurate within one fifty-thousandths of an inch.

STANDARD SCREW THREADS.

About the first and most important application of standards in machine work was to screws and screw threads. There was a time when every manufacturer made screws of whatever diameter, pitch, and shape of head happened to suit him. The disadvantage of special screw threads are feelingly described by a writer in the *American Machinist* (April 6, 1893). He says: "There lies before me a cam and its set-screw, the latter stripped. It is a set-screw, pure and simple, and has no other function in the economy of the machine than to hold that cam. The only peculiarities about it are that its head is ornamented thus, C37, and that it has thirty threads to the inch, and is $\frac{23}{64}''$ in diameter. The threads are useful, in a limited degree, for advancing the screw; the ornamentation for identification, and, in a major degree, for advancing the profits of the makers of the machine, for the catalogue, also before me, proves the identity of the fact by an excellent cut and the following text: 'Part C37; set-screw to cam C36, twenty-four cents.' Now, it is of no use to go anywhere else for that set-screw, for no sane hardware dealer keeps set-screws $1 \times \frac{23}{64} \times 30$, and the only thing to do is to wait for the part to come or bother to make one, if you have the facilities. I suppose it is a matter of ethics, rather than of mechanics, whether the makers of a machine have the right to subject their patrons to annoyance and extortion in order that their profits may be increased. If there were any good mechanical reason, I would not object to the thread, size, or price, but a $\frac{3}{8} \times 16$ screw, costing two cents, would be better for the place than the one adopted. I do not expect the breech-blocks of rifled ordnance, or the lead-screws of lathes, to be made to a standard size and kept on sale in common hardware stores; but I fail to see any good reason why so simple a thing as a set-screw should be anything but the standard size and thread."

THE WHITWORTH THREAD.

About the first standard screw thread adopted was the Whitworth or English standard. It is said that Sir Joseph Whitworth arrived at this standard by finding out the different sizes, shapes, and diameters in use at that time and taking the average. The shape of this thread is triangular, the angle between the threads being fifty-five degrees. One-sixth of the height of the triangle is cut off by an arc of a circle tangent to the sides. The diameters of the screws vary by 16ths of an inch, from $\frac{3}{16}''$ up to $\frac{1}{2}''$, and by 8ths for larger sizes. The relation between the diameter and the pitch is given approximately by the formula $p = .08d + .04$, where p = pitch and d = diameter of bolt, both in inches. The number of threads per inch $= n = \frac{1}{p}$; the nearest whole number of threads per inch being taken.

THE SHARP V THREAD.

On this side of the Atlantic the Whitworth standard has never come into general use. The chief forms used here are the sharp V and the United States standard. The sharp V was formerly almost universal, and is still used to a great extent, especially in Canada, where we do not seem to wish to follow either the English or the United States standards. The shape of the sharp V is theoretically an equilateral triangle, though in practice it is not usually brought up to a sharp edge, but left a little flat. It is not a standard thread in the sense that it has been established as such by any association or large firm, but, by common consent, manufacturers have adopted a table of diameters and pitches following those of the Whitworth standard, except for a few screws over $2\frac{1}{8}''$ in diameter. In addition to these regular sizes, there are a lot of taps and screws made with different pitches, mostly finer than the ordinary ones. Taps and dies are also made $\frac{1}{64}''$ and $\frac{1}{32}''$ oversizes for rough iron, it being the custom of manufacturers to roll iron oversize. The result of these special pitches and oversizes is that V-thread screws will not always interchange, a very serious defect.

THE UNITED STATES STANDARD THREAD.

In 1864 the Franklin Institute appointed a committee "to investigate the question of the proper system of screw threads, bolt heads, and nuts, to be recommended by the Institute for general adoption by American engineers." The committee recommended the system which had been designed by Mr. William Sellers. In this system the shape of the thread is an equilateral triangle with one-eighth of the height cut off by a line parallel to the base, giving a thread with a flat at top and bottom equal to one-eighth of the pitch. The relation between the pitch and the diameter is given by the formula $p = 0.24\sqrt{d + 0.625} - 0.175$.

While this equation gives a parabola, and that for the Whitworth thread gives a straight line, yet, within ordinary limits, there is hardly any difference. Between $d=\frac{1}{4}''$ and $d=1\frac{1}{2}''$ there is only one difference in pitch, that for the $\frac{1}{2}''$ screw, which has thirteen threads per inch in the United States standard, and twelve threads per inch in the Whitworth.

The report of the committee of the Franklin Institute recommending this system of screw threads discusses the question of a standard screw thread in such an able manner that any of you who have the opportunity should read the full report.*

Soon after the Sellers' system had been recommended by the Franklin Institute, it was adopted as the standard for the United States navy. Later, it was recommended by the Master Mechanics' Association for use in locomotive construction, and, in 1871, it was recommended by the Car Builders for use in cars. It has been adopted by a great number of railroads and large engineering firms, and is coming more and more into general use. In 1886 it was stated by the Pratt & Whitney Co., in an article puplished in the *Railroad Gazette*, that from eighty to ninety per cent. of the taps and dies sold in the United States by various dealers were of the United States standard.

Difficulties were, of course, encountered in establishing this system. A number of firms thought that the United States standard consisted merely in a certain relation of pitch to diameter, and did not make the thread the right shape. Also, as with sharp V threads, it became the custom to use taps and dies $\frac{1}{32}''$ to $\frac{1}{64}''$ oversize for rough iron. The Master Car-Builders' Association made a great effort to prevent such practices, and "to impress upon the minds of those who have control of such matters that three features are essential in the Seller's system :

"First, *screws must have a given number of threads per inch.*

"Second, *the threads must be of the form and proportions designated.*

"Third, *the diameters of the screws must conform to the sizes specified.*"†

The matter of oversize iron and steel for bolts was found to be easily solved. On the Erie Railroad they simply issued an order : "All iron and steel for bolts shall be carefully inspected, to make sure that it does not run over or under size, and bars involving double cutting, or too small, shall be rejected." As soon as the manufacturers grasped the idea that the company wanted iron nearly the nominal size, there was no further difficulty. The Master Car-Builders' Association took the matter up, and, after consulting with different ironmakers, they established a limit of variation in size. The total variation is .010 inch for ¼ inch iron (.005″ above or below nominal size). The limit of variation increases .001″ for each succeeding size of iron. The Pratt & Whitney Co. make a set of double-end caliper gauges to be used when inspecting iron for bolts. Iron which will go in the large end and not go in the small end is within the allowable limit of variation.

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*The full text of the report will be found in "Standards of Length and their Practical Application," published by Pratt & Whitney Co., p. 78 ; and in "Modern Machine Shop Practice," by Joshua Rose.

†Report of the Committee of the Master Car-Builders' Association on Standard Screw Threads. "Standards of Length and their Practical Application," p. 61.

But a still greater difficulty was encountered in establishing an interchangeable system of screws and bolts. A couple of years after the Erie road adopted the Sellers' system, it was found that some nuts made at one shop would not fit bolts made at another. An investigation showed that the threads were not only different in diameter, but even in pitch and angle of thread. The company ordered the different shops to discontinue making their own taps and dies, and to buy them from manufacturers. It was found, however, that nuts made with taps bought from one manufacturer would not screw on the taps of another manufacturer. Another investigation was made, and it was found that the screw gauges used by different manufacturers did not agree with one another, nor with the standard gauges at the Brooklyn Navy Yard. The difference was not very great, but it was sufficient to prevent interchangeability. This need not be very much, for it is stated that a difference of .002″ in the diameters of a bolt and a nut will make a very bad fit. It was thought that the difficulty arose from the fact that different manufacturers were using different standards of length. The Pratt & Whitney Co. undertook to test the matter. They procured what were supposed to be the most accurate standards in the country, and had them measured on the best measuring machines in existence. They found that no two of the standards measured alike on the same machine, and that no two machines would measure the same standard alike. As the matter was of great importance to the company in the manufacture of taps, dies, gauges, and other tools, they determined to obtain accurate copies of the standards of length, and to make a measuring machine to enable them to subdivide and compare these standards, and to test the accuracy of gauges, etc. The company secured the services of two men well fitted for this task, Prof. W. A. Rogers, connected with Cambridge Observatory, and Professor of Astronomy at Harvard College, whose name has long been associated with minute measurements, and Mr. George M. Bond, a graduate of the Stevens Institute. They designed and constructed a machine—the Rogers-Bond Comparator—to be used (1) to compare line measures of length with attested copies of the Imperial yard and the metre; (2) to subdivide these line measures; (3) to investigate and determine the errors, if any, of these subdivisions; and (4) to reduce these line measures to end measures for use in the workshop. With this comparator measurements may be made with *certainty* within $\frac{1}{1000000}$ of an inch, and readings are in *millionths*. The company also had Prof. Rogers graduate for them five standard bars, as follows:

P. & $W._1$ is a bar of Baily's metal, 41 inches long and 1 inch square. It is a yard measure, divided into feet, the graduations being on gold plugs at the bottom of wells sunk half an inch in the bar.

P. & $W._2$ is also of Baily's metal, and is the same size as P. & $W._1$ The graduations, however, are over platinum iridium plugs, sunk flush with the surface of the bar. It is both a yard and a metre standard.

P. & $W._3$ is a bar of tempered steel, and is both a line and end measure, metre, and yard.

P. & $W._4$ is a bar of annealed steel, and is of the same form and dimensions as P. & $W._3$

P. & $W._5$ is a working standard of tempered steel, six inches long and one-half inch square.

The graduations on these bars have been thoroughly investigated, and their errors determined, so that allowance may be made for them. P. & $W._1$ was found to be 53 millionths of an inch longer than the Imperial yard at 62° Fah., while P. & $W._2$ was 36 millionths of an inch shorter than the Imperial yard at that same temperature. This whole work took about five years. It was begun in 1881, and Prof. Rogers handed in his report in 1886.

Having obtained accurate measures of length, Pratt & Whitney proceeded to make screw gauges for the United States standard thread. By using these gauges in making taps or in testing taps bought from manufacturers, any firm will be able to secure that accuracy necessary for interchangeability.

As a result of the efforts of the Pratt & Whitney Co. in establishing the United States standard screw threads on a sound basis, and of the enterprise of large firms in adopting this system, it is now an accomplished fact that screws and bolts are interchangeable throughout the United States. There is still room for improvement, but chiefly in the line of adopting the United States standard and of discontinuing the use of oversize and odd pitch threads.

SMALL SCREWS.

The standard screw threads just described are for machine screws ¼″ or more in diameter. For smaller sizes there are not such well-defined standards. Machine screws smaller than ¼″ generally have the ordinary 60° sharp V thread. The diameters in use here usually follow the American Screw Gauge, the sizes being expressed by numbers. No. 1 is .07100″ in diameter, and the diameters increase by .01316″ for each size up to No. 50, which is .71584″ in diameter. Only the even numbers smaller than ¼″ are generally used, though. Makers of screws give a choice of two or three pitches for each size, and makers of taps more. For instance, No. 4 machine screws are listed with 30, 32, 36, 40, 42, 44, and 48 threads per inch. There seems lately to be a tendency among screw manufacturers to adopt a standard pitch for the even numbers. It is called the American Screw Company's standard, and runs as follows: 2-56, 4-36, 6-32, 8-32, 10-24, 12-24, 14-20.

Makers of taps also have a list of sizes varying by 64ths of an inch from $\frac{1}{16}$″ up to ¼″, but they do not appear to be much used.

Carriage bolts and stove bolts have special forms of thread. Carriage bolt threads are rounded at top and bottom, and the sides are at a slight angle. Stove bolt threads are nearly square. Some firms are trying to establish a standard of form and dimensions, but it is difficult to determine just what these standards are.

PIPE AND PIPE THREADS.

There is a well-established standard of sizes and threads for wrought-iron pipe, for steam, water, and gas. The sizes of the pipes are strangely irregular, and threads are not much better, but they are definitely known and generally followed, so that we reap all the advantages of a standard. It is so very much better to have even a poor standard than to have none at all. The Briggs standard for pipe and threads was established in 1862 by Robert Briggs, C.E., when superintendent of the Pascal Iron Works, Philadelphia. The sizes were adopted in 1886 by the manufacturers of wrought-iron pipe and boiler tubes. The action of the pipe manufacturers was endorsed and adopted by the Manufacturers' Association of Brass and Iron, Steam, Gas and Water Works of the United States. The sizes are expressed according to the nominal internal diameter. The actual internal diameters are, with one exception, larger than the nominal size. For instance, a ¼-inch pipe is 0.364″ internal diameter and 0.540″ external diameter. The thread employed has an angle of 60°, and is slightly rounded off, both at top and bottom. The taper of the threaded end is 1 in 32 to the axis, or ¾″ per foot in the diameter. The pitch varies roughly with the diameter, but without any regularity. Thus all pipes from 1″ to 2″ have 11½ threads per inch, while ½″ pipe has 14 and ¼″ pipe

18 threads per inch. The length of the threaded end, throughout which the thread continues perfect, is given by the following empirical formula: $l = (0.8\ D + 4.8)\ \frac{1}{n}$, where D is the actual external diameter of the tube throughout its parallel length, and n is the number of threads per inch.

FRENCH SCREW THREADS.

The *American Machinist* of May 30th, 1895, contains an account of the recent introduction of a standard screw thread in France which presents some points of interest. A diagram is given, with curves showing the ratio of the pitch to the diameter in both the French and the United States standards. The agreement is remarkable, and shows that the preferred practice is about the same everywhere. The pitch of the French system seems, if anything, somewhat finer than our own. The pitches of the French threads are not expressed as so many threads per centimetre or other unit of measurement, but as so many millimetres per thread. The 6 mm. (about $\frac{1}{4}''$) screw, for instance, has a pitch of 1 mm., that is, it advances 1 mm. per turn. This is equivalent to about 25 threads per inch.

The Society for the Encouragement of National Industries has long been agitating for a standard thread in France, and at last the Minister of Marine has formally notified the society that he has decided to adopt, in principle, their system of screw threads. The shape of the thread is the same as in the United States standard, namely, an equilateral triangle with one-eighth of the height cut off. The diameter of the screw is to be measured after the truncation of the triangle, as in the United States system.

The system also provides for the clearance of the threads, for the greatest variation in size of the unthreaded portion of the bolt, for screws of intermediate sizes, when such may be necessary, and for the size of bolt heads and nuts. These latter are to be inscribed in a circle whose radius is equal to the diameter of the bolt.

They have an effectual way of introducing the system. The Minister of Marine has addressed letters to the vice-admirals, maritime prefects, and directors of establishments, enjoining the use of the new system; and, after January 1, 1896, orders for new machines of all kinds shall specify the use of the new system. This latter will compel manufacturers who wish to get contracts from the navy to use the new system.

BOLT-HEADS AND NUTS.

At the time at which the Franklin Institute recommended the Sellers thread, now known as the United States standard, they also recommended a standard size for square and hexagon bolt-heads and nuts. The words of the report are :

"The distance between the parallel sides of bolt-head and nut, for a rough bolt, shall be equal to one and one-half diameters of the bolt plus one-eighth of an inch. The thickness of the heads for a rough bolt shall be equal to one-half the distance between its parallel sides, and the thickness of the nut shall be equal to the diameter of the bolt. The thickness of the head, for a finished bolt, shall be equal to the thickness of the nut. The distance between the parallel sides of bolt-head and nut, and the thickness of the nut, shall be one-sixteenth of an inch less for finished work than for rough."

These proportions are not followed very closely by makers of bolts and nuts. In five catalogues which the writer examined which contained tables of sizes of bolt-heads and nuts, not only did the tables in different catalogues differ from one another, but even in the same catalogue there were different tables of sizes. Some of these sizes were larger and some smaller than the standard, and none of them seemed to follow any rule. This standard is not of such great importance as some others, for the chief advantage of a standard size for bolt-heads and nuts is in being able to use a set-wrench. The lack of a recognized standard necessitates either a greater variety of wrenches or the use of an adjustable wrench.

WIRE AND SHEET METAL GAUGES.

This is decidedly a case where the matter of standards has been overdone. One would think that a standard of dimensions for wire and sheet metal would be a good thing, but when every manufacturer and association of mechanics think the same, and each gets out a different gauge, the result is quite confusing. It seems to have been the practice for each manufacturer of wire or sheet metal to get out a gauge suited to his business. Don't think that he sat down and wrote out in decimals of an inch the sizes he wanted, but rather that he had a steel gauge made with notches in the edge, representing the sizes he manufactured, and that he then numbered these notches consecutively in any way it happened to suit him. In some gauges the numbers get larger as the wire gets larger or the metal thicker, while other gauges are figured in the reverse order. The number of different gauges is surprising. In 1879 Hughes enumerated no less than 55 gauges, 45 of which were for measuring or determining sizes of wire used in Great Britain.

These gauges have two chief defects. They are indefinite and inaccurate. Some one has said that they have only one fault—their existence—but we may specify more particularly. They are indefinite because of their large number. No. 16 wire means practically nothing, because there are over a dozen different wire gauges in common use. No. 16 may be almost any size from .0359″ to .28150 in diameter, that is, from about $\frac{1}{32}$ of an inch to over ¼ of an inch. But even when we specify the gauge, which we must do *very* carefully, there is still a chance of inaccuracy. The notches in these gauges will certainly wear with continued use, so that even if the gauge were correct when new it would not be so long. The result is that even No. 16, by a specified gauge, is indefinite. This latter defect has been to a great extent eliminated by determining the sizes of the different numbers in decimals of an inch, and by the use of micrometer calipers in measuring wire. This makes the Imperial yard, instead of Tom Jones' gauge, the ultimate standard.

An agitation has been going on for the last twenty years or more to induce the public to abandon the use of fixed gauges and numbers, and to measure and designate wire and sheet metal by its diameter or thickness in thousandths of an inch. The difficulty of using the ordinary gauges is well described in a circular issued, in 1876, by Messrs. Miller, Metcalf & Parkin, Pittsburg:

"How is it possible for a roller to know just how many millionths of an inch another man, whom he never saw, means when he says No. 28 'full' or No. 27 'easy'? And how is he to guess how many thousandths of an inch the other man's gauge is wrong in its make, or how many hundredths it has worn in years of steady use? There is a simple and easy way out of this whole snarl, and that is to abandon fixed gauges and numbers altogether."*

More recently (in December, 1894) the committee of the American Society of Mechanical Engineers on Standard Gauges for Thickness reported in favor of abolishing the system of fixed gauges and of substituting the use of the thousandth of an inch for measuring and designating wire, sheet metal, etc. Several members of the committee, and members of English engineering societies with whom they corresponded, favored the hundredth of a millimetre as a basis, but it was not thought wise to advocate it at present.

Part of the report reads as follows: "Resolved, that we, the members of the joint committee of the American Society of Mechanical Engineers and American Railway Master Mechanics' Association, earnestly deprecate the use of any of the numerous wire and sheet metal or other trade gauges now in vogue, and strongly urge the use of thousandths of an inch for all kinds and classes of small measurements.

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*Catalogue of Brown & Sharpe Manufacturing Co., p. 361 (1895).

" In practice we recommend the use of micrometer callipers or notched gauges, the latter with notches of dimensions suited to the convenience of different industries, and, where necessary, different selections of sizes in thousandths of an inch, suited to each trade, being incorporated in their working gauges; provided, however, that they are always dimensioned in thousandths of an inch, and marked in terms thereof, the number of thousandths being marked opposite each gauge notch thus, .001″.

" We further recommend that the members of the various engineering societies assist the introduction and general adoption of this system by using it in their own work."

One would think that such efforts would have a tendency to kill off some of the numerous gauges, or, at least, to prevent the origination of new ones. This does not seem to be the case, however. For instance, the Standards Department of the British Board of Trade issued a new table of sizes for wire, to be the legal standard after March 1, 1884. It is not the actual standard, however, so that it merely adds one more to the list. More lately still, in 1893, the United States Congress passed a bill authorizing a new gauge as the only legal gauge for plate iron and steel. This gauge has one or two minor advantages, but otherwise it is even a little worse than the worst of them.

We seem, then, to be about as far as ever from abolishing fixed gauges. This much we can do, however, in ordering or giving the size of wire or sheet metal: let us always give the diameter or thickness in thousandths of an inch, instead of by gauge number. This will not only advance the cause of science, by rendering arbitrary gauges useless, but it will serve to protect those who practise it from annoyance and loss, as numerous mistakes arise from a misunderstanding of the size intended, when it is specified by a gauge number.

We have considered but a very few of the standards in use, but you will readily understand how impossible it would be to adequately treat of the subject in a short paper, even were the writer qualified to do it justice. At present, most of the information on this subject is scattered through numberless machine shops, periodicals, catalogues, pamphlets, books on machine design, etc., which, if collected and put in book form, would doubtless prove of great interest and value.

For the convenience of any who may wish to refer to tables of dimensions of different standards, a list of references is appended. As far as possible, these references are to catalogues, as these are cheap and easily obtained.

Catalogue of Brown & Sharpe, Providence, R.I.

Wire Gauge, American, or Brown & Sharpe.
" Birmingham, or Stubs'.
" Washburn & Moen Manufacturing Company's.
" Trenton Iron Company's.
" Stubs' Steel.
" Twist Drill and Steel (actual average sizes of Stubs' Steel Wire).
" Steel Music.
American Screw Gauge.
United States Standard for Iron and Steel Plate.
" " Screw Thread.
Standard Gears.
" T Slot Cutters.

Catalogue of Pratt & Whitney Co., Hartford, Conn.

Pipe and Pipe-Threads, Briggs' Standard.
Limit Gauges for Round Iron.
Standard Taper Pin Reamers.

Catalogue of the J. M. Carpenter Tap and Die Company, Pawtucket, R.I.

Pitches for United States Standard, Sharp V, and Whitworth Threads.
" for Machine Screws (American Screw Company's Standard).
" for Stove Balt Taps " " "
Drill List for Machine Screw Taps.

Catalogue of Rice Lewis & Son, Limited, Toronto, Canada.

Imperial Standard (New Birmingham) Wire Gauge.
Gauge for Russia Sheet Iron.
Weight of Round, Square, and Flat Bar Iron.

Catalogue of Rhode Island Tool Company, Providence, R.I.

Square and Hexagon Nuts, United States Standard Sizes.
" " Additional Sizes.
Washers, Standard Sizes.
" Additional Sizes.

Catalogue of Morse Twist, Drill, and Machine Co., New Bedford, Mass.

Tap Drills for Sharp V, United States Standard and Whitworth Threads.

Catalogue of Chas. H. Besley & Co., Chicago, Ill.

London Wire Gauge.
Brass Tubing, Sizes and Weights.

Modern Machine Shop Practice, Joshua Rose.

Gauge for Russia Sheet Iron.
American Zinc Gauge.
Belgian Zinc Gauge.
Birmingham Gauge for Rolled Sheet Silver and Gold.

THE CHICAGO CANAL, AND SOME SANITARY PROBLEMS CONNECTED THEREWITH

By Dr. P. H. Bryce, M.A., Toronto.

Probably most people know the character of the work on the Chicago Canal from an engineer's standpoint better than I do, but you may not have learned the reasons why it has been undertaken as a sanitary work. As you are aware, Lake Michigan has a height of 579.60 feet above sea level at Sandy Hook, and is some two feet higher than Lake Huron. The waters of the lake at Chicago are separated from those of the Des Plaines River, which flows into the Mississippi River, by some two miles only of a watershed. The elevation of this land between the two greatest water systems of the continent is only some six or eight feet, and is, indeed, so little that in the construction of the canal a spill-way, or the river diversion works, has had to be planned, whereby the lower portion of the valley of the Des Plaines will, during flood time, be relieved of the flood waters in the upper reaches of the river, when they exceed 600,000 feet per minute, by their being turned into the lake through this aqueduct, some twelve miles long and two hundred feet wide, and having a fall of six feet to the mile.

The little stream called the Chicago River, at its nearest point, only two miles from the Des Plaines River, empties into Lake Michigan at the south end of the lake, and has become naturally the great central sewer of the city ; while Lake Michigan, by nature a beautiful clear blue water, is as naturally the source of the Chicago water supply. Thus most of the broad facts of our lesson are before you. The city of Chicago, as you are aware, has had a remarkable history of growth and development. Fifty years ago it was a great marshy tract at the head of the lake, with only a few Indian huts here and there.

In 1870 its population was........ 298,000, say 300,000
" 1880 " " .... 593,000, an increase of 66 per cent.
" 1890 " " ....1,100,000, " " 120 "

With the invariable history of the cities on our inland waters, Chicago began years ago to find, as her population increased, that the short intake pipes laid into Lake Michigan were supplying other materials besides the pure lake water; and so we have the history of, first, the extension of pipes into the lake, and, second, the construction of a tunnel with the hope of obtaining a water taken beyond the point of pollution of the waters with sewage; but all was in vain.

Then a scheme was thought of, which was to divert the sewage by pumping it over the watershed out of the Chicago River and into the Des Plaines valley. This accomplished some good, but it was found that it only required a heavy rain to fill up the sewers, when the river became filled, much beyond the capacity of the pumps, and the black stream began to pour again into Lake Michigan. Thus it was soon felt that no mere temporary expedients could avail, and the Chicago engineers sought some permanent remedy. This was first in the shape of a great aqueduct out some four miles into the lake, and that the case was urgent is seen in the fact that in 1891 there were recorded some 1,700 deaths from typhoid in a city of 1,000,000 or so inhabitants. This tunnel was completed in 1893; but with six other pumping stations, with local sewers at no great distance from their intakes, only partial improvement was possible.

Along with this tunnel scheme was conceived the idea of constructing a great sewer to the Mississippi, which would flow at all times. This is being rapidly constructed. It is to have an ultimate maximum capacity of 600,000 cubic feet per minute, with a depth of from 22 to 35 feet. Its uniform width in the rock section is 162 feet, and will be 200 feet in the earth portions when completed. There can be no doubt of its being a great and costly work, but, as is apparent, it is simply the cutting of a great canal through clay, black loam, and an easily worked limestone. The State of Illinois, by legislation in 1889, provided for the incorporation of the Sanitary District of Chicago, and granted a permit for the work to be carried on, having a beautiful and sublime disregard for any one but the good people of Chicago, who, getting tired of drinking their own sewage, proposed to supply it to all the dwellers along the Father of Waters down to its mouth.

In return for any incidental inconvenience from this source, they said, in effect, to said dwellers on the Illinois and Mississippi, "We will supply you with a foot more water to float boats in and improve your commerce"; and to the people living in the other cities and towns, and who go to the sea in ships and do business on the great lake waters, and who are suffering from chronic low water, at the Limestone crossway, in the Detroit River, and elsewhere, "Don't be disturbed if we rob you of the one-twenty-fifth of the total water which flows down the Detroit River, since, at any rate, the Chicago people will be happy and healthy."

Setting aside, however, all but the sanitary problems attaching to this great work, we can see in them the following immediate effects :

(1) The great sanitary improvement of Chicago, if the lake is freed from sewage pollution and pure water is supplied to the citizens.

(2) A certainty of the pollution of the Illinois River, already bad, even at Joilette, some thirty miles down, owing to the sewage from the present pumping works.

(3) An immediate and definite lessening of the volume of water which receives the sewage of the towns along the St. Clair, Detroit, and Niagara Rivers.

It is of interest for us to estimate what the pollution of the river at Joliette will mean, and we can understand this by estimating the degree of dilution of the sewage by the waters which will flow through the canal from the lake. As already stated, the estimated flow through the rock section at its maximum capacity will be 600,000 cubic feet per minute, or 864,000,000 per diem. It is calculated that this will be realized with a population of 2,000,000. Assuming this population, and a flow of one hundred gallons per head of sewage in the canal, we find that 200,000,000 gallons of sewage per diem equals a flow, including the extra amount from rainfall on the streets, of one hour's flow of the canal. In other words, the dilution of the sewage will be 1 in 24 parts. If we compare this with other cities, we find that Pettenkofer states that in the Isar, at Munich, the sewage is 25 per cent. of the river flow, and considers this a sufficient dilution to remove all nuisance. Stearns, the engineer of the State Board of Massachusetts, does not consider that 1 in 40, or even 1 in 120, can be accepted as a standard under all circumstances at which rivers may receive sewage pollution. This is in the matter of the creation of a nuisance only, and is not intended to refer to the potability of a river water for a public supply. It is quite apparent, therefore, that the pollution of the Illinois River, in its upper portion, at any rate, will be beyond redemption ; and, as has already happened, we may expect the question of damages to towns below to crop up at every stage.

As compared with such pollution, that of the St. Clair, the Detroit, or the Niagara, might be described as accidental ; but we already know that the dilution in eighteen miles from Buffalo to Niagara Falls, or the diffusion in five-eighths of a mile between Walkerville and Windsor intake, roughly calculated as 600 times, has not removed the danger from sewage, if it contain the germs of typhoid fever.

The case of Chicago, situated on a lake, in a position similar to Cleveland, Toronto, etc., is an interesting and instructive one, since it supplies us with a sequence of conditions which have in a smaller degree been realized by all lakeside cities and towns between Chicago and Kingston. The manifest first source of danger is the increase in the population of these cities. The cause of this is a natural one, since in 1890 our great lake system of waters carried 20 per cent. of the tonnage of the water-borne freight of the United States, and in 1893 26½ million tons passed through the Detroit River. But more than this, we find that over 90 per cent. of the cities of over 10,000 in the United States and Canada are situated on navigable waters.

Thus those on the Great Lakes increased in the years between the census of 1880 and of 1890 as follows :—Wisconsin, 43 per cent. ; Minnesota (Duluth), 38.56 per cent. ; Michigan, 73 per cent. ; Ohio, 40 per cent. ; Pennsylvania, 46 per cent. ; New York, 37 per cent. ; Indiana, 46 per cent. Michigan (those on Detroit River), 83 per cent. New York State (on Niagara River), 63 per cent. Canadian side (on Detroit and Niagara Rivers), 38 per cent.

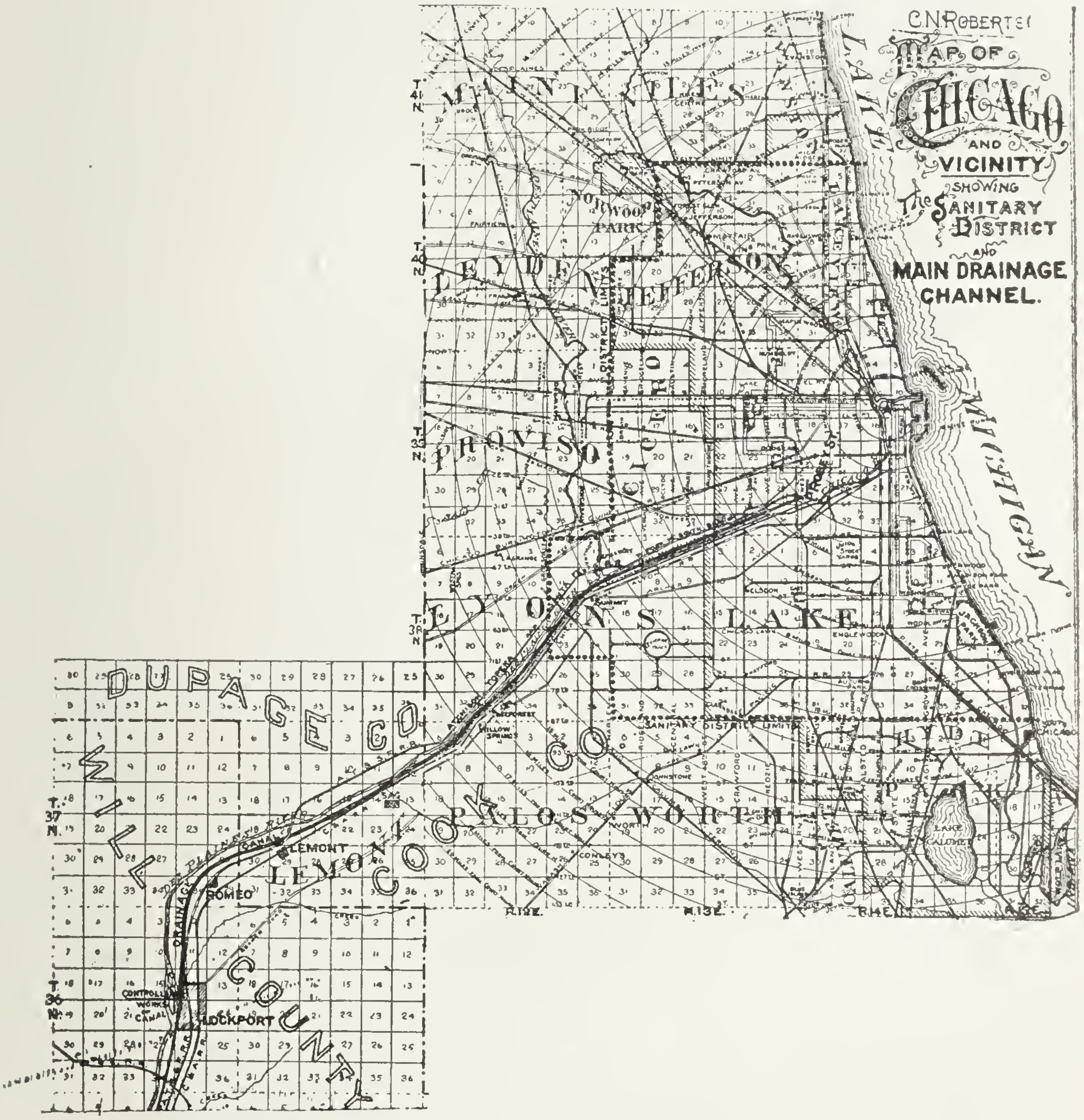
We therefore find that as municipal operations are always behind public needs, we have constantly public water supplies deficient in quantity, and very often in quality. And that, in addition to this, there is invariably a pollution of even large bodies of water, which, in spite of oxidation and the decomposition and nitrification of the organic matters in sewage, establishes a factor of permanent pollution in the lake waters near such cities.

These two results of city building are constants, and to engineers they supply the most ample field for the exercise of their talents in making the best use of present methods, and of developing others for the effective dealing with the difficult problems which are constantly cropping up in regard to water supply and sewage disposal.

In a paper read before the American Public Health Association, recently, in Denver, I illustrated by these facts the need of International Rivers Conservancy Boards to prevent notably the evils arising from polluted water supplies, but also those political dangers so readily created and solved only with such great difficulty.

The directions in which we have to look for dealing effectively with these two conditions are, of necessity, two—and, broadly, two only. Which shall we put first ?

It would be largely true that, if we could supply unpolluted water to our cities, we need not be very anxious as to whether a few hundred thousand gallons, more or less, of sewage were carried into our great lakes and rivers. But even then it is found, as in Glasgow, that tidal streams may attain to a degree of foulness which makes them sources of nuisance and positive danger for the neighborhoods through which they pass. I anticipate such will be found in the instance of the Chicago Canal. But can we afford to depend upon our water supplies without any attempts to deal with sewage as well? In the instance of Chicago, artesian waters have been found available for some of the towns and cities along the Illinois River; others have or will be forced to put in filtration works, which may or may not purify. It seems quite possible, however, to supply these towns by a common water pipe carried from Lake Michigan, but it will be expensive. We may then consider whether it would have been



possible to deal with Chicago sewage in any other way than that proposed.

At Pullman, 40 miles away, the sewage has for years been purified by irrigating the land ; could Chicago have done the same? There were, so it was stated by statistics, during the winter of 1894, 150,000 people unemployed. Everywhere outside of the city, and notably in the valley of the Des Plaines, great tracts of prairie land are lying uncultivated or nearly so. Is it not a practical question to discuss whether, with some of the engineering skill utilized in making the canal, a system of dealing with sewage by a sewage farm, as at Berlin, Germany, could not have been instituted, which by irrigation would have given employment and homes to many thousands of people now supported by charity, or, for public safety, by the municipality? The utilization of the waste organic products of cities has become the characteristic work of the great municipal engineers of Britain and Germany, and their labors have made of them philanthropists to a degree which, perhaps, has not to any other class been possible. Should we apply it to the case of Toronto, what would be possible? The utilization of land which bountiful Nature seems to have supplied especially for our needs! Hundreds of acres are lying around Ashbridge's Bay, and acres more forming every year, and demanding our attention. Our beautiful bay is increasingly a cesspool. Surely, when we have thousands of unemployed, permanent employment to hundreds can be given by allowing them to labor at the work of cultivation on a great sewage farm. This is one amongst many of our unsolved municipal problems.

In the other work of the purification of water, we have in Ontario an equally great need, and are, perhaps, at a more doubtful stage. The principles underlying each work are the same, but the reasons urging work forward are different. Each town hopes to be able to dispose of its own sewage cheaply, by simply turning it into the nearest stream, but is often prepared to spend much to purify water polluted by another town. It seems very clear, then, with these facts before us, that as sanitary engineers our energies will be directed with the greatest effect towards designing schemes comprehensive in character, and which, like township drains and irrigation works, are instituted on the assumption that the common need, and not that of some individual, or individual town or city, has interests apart from those of the general community. With the cultivation of such a spirit, it becomes easy to see how, not only intermunicipal and interstate interests may be provided, but also how the questions of international importance will be found of easy and simple solution.

DOUBLE TRACK TUNNEL, HAMILTON—TORONTO, HAMILTON & BUFFALO RAILWAY

By J. Chalmers, Grad. S.P.S.

Before taking up the construction of the tunnel, it will be well to give a short description of the road and its construction.

The Toronto, Hamilton & Buffalo Railway is a new railroad system, part of which is now in operation. Beginning at Waterford, on the Michigan Central Railway, the road extends eastward through Brantford to Hamilton, where the centre of the system is located. From Hamilton it continues in a southeasterly direction, until it again joins the Michigan Central at Welland, on which road running powers are granted into Buffa'o. The part yet to be built is the connection between Hamilton and Toronto.

Up to the year 1894, Hamilton had but one outlet by rail—the Grand Trunk Railway. For a city of 40,000 inhabitants this was considered a hindrance to its growth and prosperity—competition, the life of trade, applying to railways as to other departments of commerce.

About this time the Toronto, Hamilton & Buffalo Railway Company offered to build and operate a first-class road between Waterford and Welland, passing through Brantford and Hamilton, making the latter city the centre of the system, if Hamilton would grant assistance in the way of a bonus. In October, 1894, the city voted to the road the sum of $225,000, on condition that the said company would build and have in operation by December 31st, 1895, a road as described above. In addition, a franchise was granted giving the company a right of way along one of the streets.

Previous to this, the Toronto, Hamilton & Buffalo Railway Company had purchased the Brantford, Waterloo & Lake Erie road, running between Waterford and Brantford, which road now forms part of the present system. Work was begun between Brantford and Hamilton soon after the by-law was passed granting the bonus, and was vigorously pushed forward unto completion.

On the 24th of May, 1895, the road was opened for traffic between Hamilton and Waterford, the first passenger train conveying the 13th Battalion through to London. On the Welland branch location was begun in March of the same year, in July construction commenced all along the division, and by the end of December the grading was completed, the track laid, and a train service between Hamilton and Buffalo.

The location of Hamilton, surrounded, as it is, by the Niagara escarpment, having here an altitude of 600 feet above Lake Ontario, makes access by rail difficult from either the south or west. As both terminals of the system lie on top of the escarpment, it was necessary to overcome this altitude on both the Brantford and Welland divisions. On the Brantford division the line begins to ascend the escarpment about four miles west of Hamilton, and reaches the summit six miles further on. The maximum grade on this division is 1.5 per cent., while the maximum curve is 6 degrees.

From Hamilton to the summit the grading was heavy, the cuts being mostly hard clay, with a small percentage of rock. From the summit on to Brantford the work was comparatively light, with the exception of a large cut at Cainsville, where the line passes under the Grand Trunk.

On the Welland division the line leaves Hamilton from the east, and follows the foot of the escarpment for about three miles, where it turns southward; leaving the escarpment and crossing a slightly rolling country, it strikes the escarpment again seven miles from the city. From here it ascends about uniformly to the summit, five miles further on, the maximum grade being 1.04 per cent., compensated for curvature (ratio 0.045 feet per degree of curve). From the summit the line takes a southeasterly direction toward Welland, and, with the exception of two small curves, is carried through on a tangent to where it joins the Michigan Central Railway. The country here is flat and almost clear of wood, giving easy grades and light work on construction. The heaviest cutting was ascending the escarpment, in which lime and sandstone rock was encountered, the former in beds varying from three to sixteen inches.

The bridges on this division are steel, and, with the exception of one over the Welland River, are of the plate girder type, the other being a pin-connected truss of 150 feet span. The width of the roadbed is 22 feet in cutting, and 17 feet 6 inches on fills. The track is laid with 3,000 ties to the mile, and 80-pound rails used, fastened with suspended joints connected by four-bolt fish plates. When the Toronto branch, now under consideration, is complete, a through connection will be formed between the Canada Pacific Railway, at Toronto, and the Michigan Central, at

Welland and Waterford, making direct connection with all eastern and western cities, and placing Buffalo within two hours' ride of Toronto.

The heaviest work was encountered in Hamilton, where the road crosses a ridge or hogsback, which extends from the foot of the escarpment, across the centre of the city to the lake, through which it was necessary to tunnel. Through the city the road is double-tracked. Considering James street, where the central station is located, the central point of the system, the track follows eastward along the north side of Hunter street, the use of which was granted to the company for a distance of 800 feet. Here it crosses the street and continues in a southeasterly direction to the foot of the escarpment, there crossing the Hamilton & North-Western Division of the Grand Trunk on a level crossing. From there the line passes eastward along the foot of the escarpment to the city limit. East of James street all streets are crossed by level crossings, which are protected by gates operated from elevated signal towers over the tracks. Electric bells are placed in each tower, and connections made with the track on either side, at a sufficient distance away to give the signalman timely warning of the approach of a train.

TUNNEL AND APPROACHES.

West from James street, the line continues along the north side of Hunter street, to where it enters the east approach of the tunnel. One of the main street car lines crosses on James street, and 400 feet further west the Hamilton and Dundas suburban line crosses at McNab street. In addition to gates, these crossings are protected by derailing switches, and all trains are required to come to a full stop before crossing.

The east approach of the tunnel commences at McNab street, and is 400 feet in length, the cut gradually increasing in depth, until at Park street, where the tunnel begins, a depth of 13 feet is reached. Charles street, which crosses about the middle of the approach, is lowered about five feet to the level of the track, and protected by gates similar to the other streets.

Before entering the tunnel the line is thrown over on a five-degree reverse curve, to coincide and be parallel with the centre line of Hunter street, the tangent of which it follows for a distance of 3,200 feet, to the end of the west approach—the junction of the Brantford and Toronto divisions, the former diverging to the left on a six-degree curve, and the latter on a five-degree curve to the right.

The tunnel, known as an open-cut double-track tunnel, is located along Hunter street; the extreme length from outside face of portals is

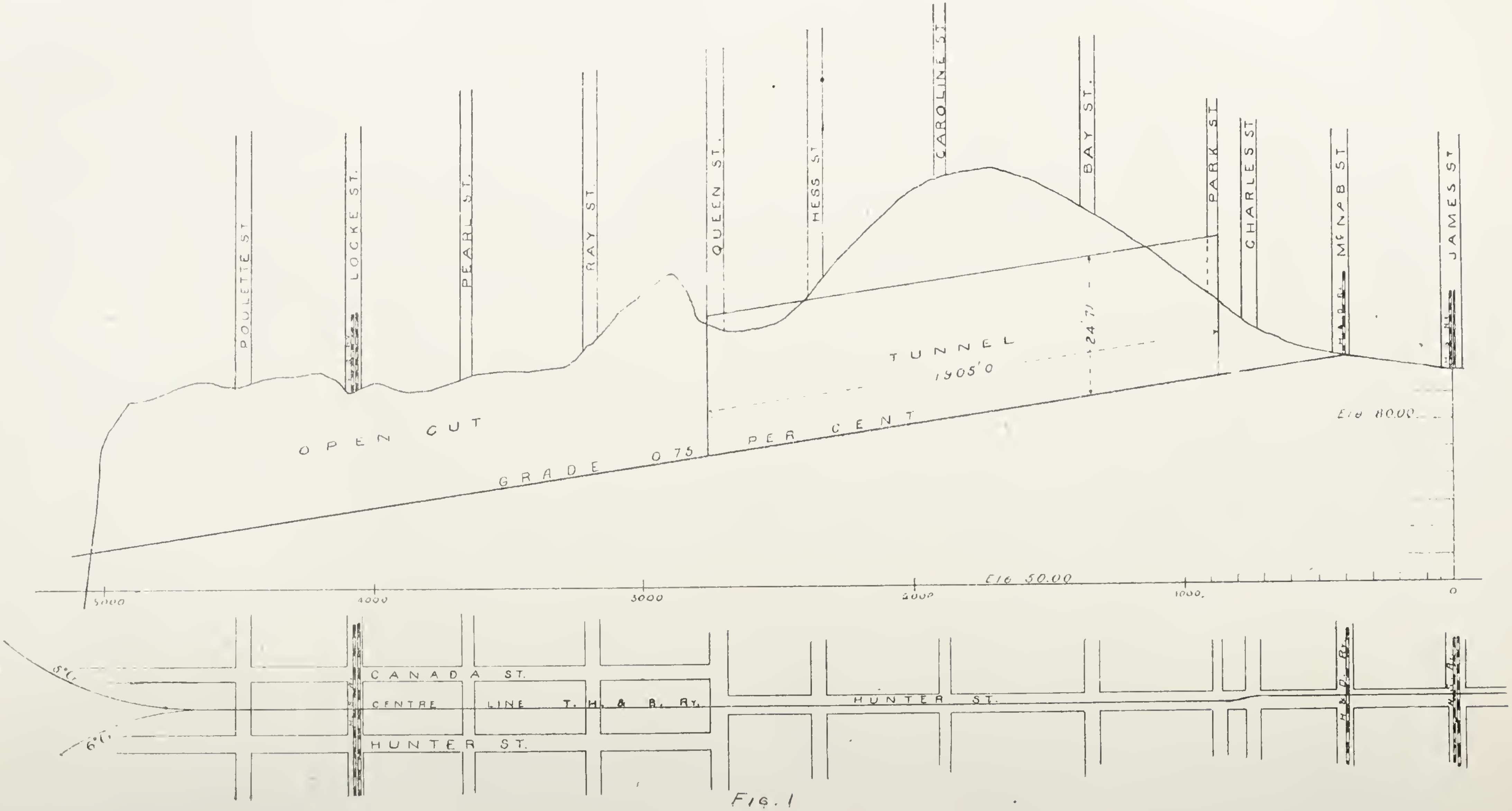

POULETTE ST
LOCKE ST.
PEARL ST.
RAY ST.
QUEEN ST.
HESS ST
CAROLINE ST
BAY ST.
PARK ST
CHARLES ST
McNAB ST
JAMES ST
TUNNEL
1905'0
24.71
El. 80.00
OPEN CUT
GRADE 0.75 PER CENT
El. 50.00
5000
4000
3000
2000
1000.
0
CANADA ST.
CENTRE LINE T. H. & B. RY.
HUNTER ST.
HUNTER ST.
5°C.
6°C.

Fig. 1

1,905 feet, with an extreme width of 37 ft. 6 in. The street is 66 ft. wide, and closely built on both sides with dwelling-houses, which extend out to the street line. The work is masonry throughout, with the exception of 80 feet of steel arch at the east end. For cross-section and details see Fig. 2. Along the outer edge of the boulevards were full-grown shade trees, a few of which were saved, while in the centre of the street were sewers, gas and water mains. Wherever possible new house connections were made direct with other sewers; but where this could not be done new sewers were laid along the back of the property affected to the nearest cross street, where connection was made with the permanent sewerage system. The gas and water mains were moved on to the boulevards, the former carried by overhead pipes across the street, and surface connections made with the house services, while the latter was laid temporarily underground until the street was restored to its original condition.

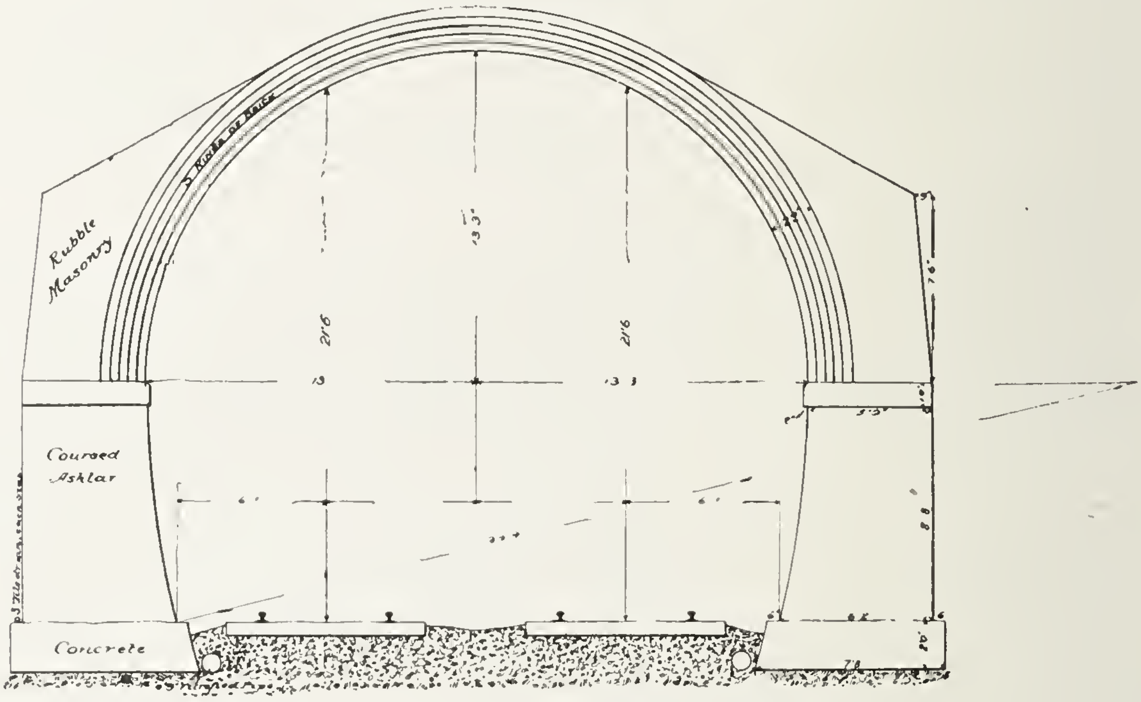
About the middle of June the contract was let, and work commenced toward the end of the same month, the tunnel to be opened for traffic by the end of December, the same year.

Under the terms of contract, the contractor was to take the location of the purposed work as he found it, remove all paving, macadamizing, sidewalks, trees, telegraph and telephone poles within the street lines, and the contractor, at the close of the work, to restore any alley or lot which may have been occupied or obstructed to its original condition at his own expense; also, to restore the paving, sidewalks, and poles, and put the same in as good a condition as before commencing the work.

Throughout the tunnel and approaches the grade is 0.75 feet per hundred, beginning at McNab street, as shown in Fig. 1. Just east of Caroline street the maximum depth of 47 feet is reached, gradually decreasing, until at Queen street the bottom is 25 feet below the surface. On the west side of Queen street the tunnel ends, and from there west is an open cut for a distance of 2,250 feet, having an average depth of 26 feet, width of roadbed 35 feet, and side slopes, 1 vertical to 1½ horizontal. Four streets carried on overhead bridges cross the west approach. These bridges are framed structures, resting on piles, and are the full width of the streets. At Queen street the line leaves Hunter street, where the latter takes a jog to the south, as shown on the plan, Fig. 1, and passes through the centre line of a tier of blocks of private property, which was for the most part closely built with dwelling houses, a few of which were removed bodily, the rest torn down and disposed of in the easiest manner.

NATURE OF MATERIAL.

The nature of the material varied through successive grades from quicksand to rock. From McNab to Park streets the soil was a sandy loam, easily excavated. At Charles street a bed of cemented gravel was reached about eight feet below the surface, gradually approaching the top, until at Bay street there was a covering of but two feet of alluvial soil. The gravel bed at Bay street reached a depth of 30 feet, and was composed of drift boulders and gravel, varying from fine beach gravel to stones one foot in diameter, the whole cemented in one solid mass. The cementing material was carbonate of lime held by water in solution, and deposited on the pebbles, in some instances to a thickness of 0.10 of an inch, binding the whole compactly together. Midway between Bay and Caroline streets the cementing material disappeared, and the gravel became more stratified. For a depth of from 15 to 20 feet the strata was conformable with the surface, while below this it assumed an inclination to the horizontal of about 30 degrees sloping toward the west. This formation extended to Ray street, where it ran out to the surface. Underlying this concrete was a strata of water, carrying quicksand, from 2 to 5 feet in depth, and of a treacherous character. Imbedded in this, and immediately below the cement gravel, just west of Bay street, were found masses of driftwood, mostly roots and branches of trees, and, in one instance, some bones evidently belonging to the mastodon family, which were, however, in such a decayed



Cross Section of Tunnel
T H & B Railway
Fig 2

condition that they crumbled on removal. The wood, however, which was cedar, was comparatively sound and in a good state of preservation.

From Ray street to the end of the west approach the surface material was a stratified clay, deposited in horizontal layers. The soil stratum from Bay to Poulette streets consisted of a blue boulder clay, very hard and tenacious in character; this reached an average height of 9 feet above the bottom of the tunnel. From Poulette street to the end of the west approach was a hard Medina shale, reaching to within 6 feet of the surface and dipping both ways at about an angle of 20 degrees. Overlying this again at the west end was boulder clay and cemented gravel similar to that in other parts of the cut.

EXCAVATION.

With the exception of what was taken out by steam shovels, the material was all excavated by hand. From the east approach to near Bay street it was loaded into wagons in the cut, and taken to fill up low land in the vicinity. The tunnel was excavated to grade from the end by a series of lifts, 6 to 8 feet in height, working out to an open face. This method was especially advantageous in the hard material where blasting was required, which was the only means of loosening up the cemented gravel. Owing to the close proximity of houses on both sides of the cut, blasting operations had to be conducted with great care in order to avoid damage to property. The usual method of procedure was to drill a row of holes at some distance back from the face of the lift, the nature of the material determining their position, to a depth of 4 to 8 feet; light charges of dynamite were put in and connected with a battery by which they were fired; heavy timbers were piled over the charges to prevent the rock from flying, and during the three months that blasting was carried on no serious damage was done to any building along the work.

When wagons could be no longer used in the cut, a large derrick was erected at Bay street, and the material hoisted out in buckets, each bucket holding from 25 to 26 cubic feet. The style of derrick was the ordinary stiff leg type, mast 14 inches in diameter by 45 feet long, boom the same diameter by 30 feet in length, with boom and fall ropes ⅞ inch steel cable, and operated by a 16 horse power double drum hoisting engine. On the bank a platform was erected, about 12 feet square, high enough to allow a wagon to drive underneath, in the centre of which was a hopper, with a three-foot opening in the bottom. On this platform two men were stationed to empty the buckets into the hopper, which discharged into the wagon box below. A sufficient number of buckets was used to cause no delay in hoisting, and under favorable conditions 30 cubic yards of material could be excavated per hour, the number of men employed depending on the hardness of the material. When the working face got beyond the reach of the boom, tracks were laid in the cut, and cars used to convey the buckets ; the economic length of track not exceeding 200 feet. Later on derricks of a similar type were erected at convenient points along the work, and excavation carried on in the same manner.

The west approach, and also the tunnel, for about half the depth, as far as Bay street, was excavated by steam shovels—two shovels working in this section until November. This material was loaded on cars, and taken three miles out on the Brantford division, where it was used to fill a trestle bridge over a deep ravine. After the steam shovel had finished between Bay and Caroline streets, a Lidgerwood cable conveyor was erected to complete the excavation. This consisted of two towers, 70 and 50 feet high, erected 450 feet apart, the larger set in the bottom of the cut, while the smaller one rested on the tunnel at Bay street. The towers were the shape of an inverted V, 25 feet wide at the base, and made of 12 x 12 inch timbers firmly framed together, and braced horizontally and diagonally by 3 x 12 inch plank. A 1½ inch steel cable was stretched over the towers and firmly anchored at both ends. An endless ⅝ inch steel cable, called the carrier rope, passed over a sheave in each tower, and connected with the operating engine, which was a 20 horse power of the double drum type, manufactured by the Lidgerwood Cable Co. To this carrier rope was attached the "skip," a steel frame, which travelled on the main cable, to which the fall rope blocks were attached. To prevent the fall rope sagging when the skip was run out from the head tower, light steel frames or suspenders were used. These were 4 feet long, with a small pulley in the lower end, on which rested the fall rope, while the suspenders were carried by a ½ inch steel rope, on which, at regular distance, were fastened steel stops, or buttons, 5 inches long, and varying in diameter from ¾ to 1¼ inches, the smallest being fastened nearest the front end. In the hangers were corresponding stops or openings, arranged so that the button on the rope would pass through the first and retain the last. These were carried on a projection in front of the skip, and, as it travelled back along the cable, the suspenders were caught and retained by the several buttons, until the skip on its forward movement would again pick them up.

At first automatic dumping buckets were used, holding 70 cubic feet, but these did not work well, owing to the sticky nature of the material, besides producing too much sag in the main cable. Buckets similar to those used on the derricks, and holding 1¼ cubic yards, were then used, and men were stationed on the dump to empty and spread the material. The capacity of the conveyor was about 20 buckets per hour, with the traveller moving at the rate of 400 feet per minute.

After the excavation between the towers was complete, they were taken down and not re-erected, as the amount of the material then in the cut would not warrant the cost.

Of the different methods of excavation employed, the derricks proved the most satisfactory, as they could be quickly moved, re-erected, and operated in a small space.

SHORING.

Where the excavation was concrete the banks stood up vertical without any support; the only precaution necessary was to see that no loose stones fell and injured the workmen below. In the boulder clay some trouble was experienced from portions of the bank falling into the cut after the bottom had been trimmed out for the walls, leaving an overhang of from 2 to 3 feet in the hard material. This was caused by pressure from above, assisted by water in the quicksand overlying the clay. As no supports could be applied, the clay just reaching the top of the abutment walls, the toe of the banks was left projecting out, and trimmed off as the masonry advanced. As soon as the walls were built all pockets behind the walls were immediately filled with clay, and rammed solid to prevent further accident.

From 100 feet west of Bay street to Queen street, the banks had to be strongly supported. A light shoring was put in as soon as the steam shovel got low enough that its working did not interfere with the bracing. This was made of five 2-inch planks, 12 inches wide, firmly nailed together to break joints, and cut to the required length. These were placed from 12 to 16 feet apart, and held in place by wedges driven against a plank, placed vertically at the ends. As the depth increased, additional support was required. The shoring was rearranged to form a series of trusses, made by placing the transverse braces vertically over each other, 8 to 10 feet apart, adding an additional brace as soon as the depth of the cut would allow, the whole tied together by diagonal and vertical braces of 2 by 10-inch plank. These trusses were placed every 12 feet, and firmly braced to each other. Between the end of the braces and the bank, heavy planks were placed horizontally, behind which was driven a close sheet piling, extending to near the bottom of the cut.

This arrangement of bracing proved fairly satisfactory while the dry weather continued, but after the banks had become saturated with rain, and loosened by repeated freezing and thawing, the support did not prove strong enough, and some serious slides occurred. The bracing did not appear to have sufficient stiffness in the individual members, due partially to their small cross-section, and also being built of plank instead of solid timber. Failure always occurred by the streets bending horizontally under pressure, the defection rapidly increasing, as but little resistance was offered to this motion. Another source of weakness was the difficulty of getting the pressure equally distributed; the streets acting, more or less, independently of each other.

Toward the close of the work, and before the abutment walls were completed, it became necessary to modify the lower shoring, to allow trains to pass through. This was done by placing mudsills, 12 by 12 inches, 20 feet long, across the bottom of the tunnel, 6 feet apart. Against the ends of these were erected posts of the same length and dimensions as the mudsills, while across the top, between the posts, were streets of the same size. This formed a rectangular opening, wide enough to operate two tracks in, and facilitate the passage of trains without hindering the work. Behind the posts were short streets supporting the sheet piling, as before described.

The slides that occurred were not altogether due to the weakness of the supports, the banks not falling forward into the cut, but dropping vertically downward. As the excavation got through the quicksand and into the clay, the sand would commence to run, taking away the support of the upper material, which would press downward, thereby loosening the shoring and causing the whole to collapse. The trenches made for the water mains along the boulevards also formed a weakness in the banks, which invariably sheared off along this line.

MASONRY.

The tunnel is masonry throughout, with the exception of 80 feet of steel arch before mentioned, and is built to the dimensions shown in Fig. 2. The retaining walls on Park and Charles streets, together with the spandril wall of the arch, is third-class masonry, or rubble work; while the abutment walls of the tunnel and retaining walls at east and west portals are range ashlar. The portals are cut-stone masonry, hammer dressed, and of the design as shown in Fig. 4.

Limestone was used for all stone masonry. That for the abutment and retaining walls was supplied from the Longford quarries, while the stone used in the portals was supplied from Beamsville. The Longford stone is a fine-grained, compact variety, possessing an average crushing strength of 20,800 pounds per square inch; of a pale, bluish-gray color, with some crystals or calcite; and effervesces strongly with acid, leaving no residue in the test tube. It is quarried in beds of from 4 to 28 inches, and of any size up to six feet square. The Beamsville stone is an open-grained, porous variety, pale gray in color, and crushes at 13,085 pounds per square inch; it contains a varying percentage of sulphur, and, when tested with acid, leaves considerable residue in the tube.

The arch is built of selected hard burnt brick, five rows in thickness, and covered with Trinidad asphalt.

FOUNDATIONS.

The substratum on which the foundations rest is a uniformly hard boulder clay, impenetrable by water, and not likely to produce unequal settlement. With the exception of a short distance in the centre of the tunnel, the foundation material is concrete, with a minimum thickness of 2 feet 2 inches. On the approaches, the top elevation of the concrete, with respect to sub-grade, varies according to the location; under the portals the top is 2 feet 6 inches below sub grade, and 2 feet thick, while, throughout the tunnel, the foundation reaches one foot above sub-grade, and level with the base of the rail, as shown in Fig. 2. From the east portal, for a distance of 200 feet, where the bed of the tunnel passes through the quicksand previously mentioned, the foundations were carried down to the clay, which did not exceed more than 5 feet below the normal surface.

For concrete, the specifications called for one part of Portland cement, two parts clean sharp sand, and four parts broken stone, the stone to be clean, and broken not to exceed cubes of 2 inches, or less than ½ inch, the whole properly mixed and laid in courses not more than 9 inches thick.

The concrete was mixed by hand, on platforms 10 by 12 feet square, kept close to the foundation pits; the stone, sand, and cement sent down in shutes from the top, and wheeled on to the mixing board as required. A batch usually consisted of 4 cubic feet of cement, 8 cubic feet of sand, and 16 cubic feet of broken stone. The sand was first spread evenly over the board, the cement added and thoroughly mixed; enough water was then added to make a thin mortar, which was again evenly spread out. Stone was then added, first being thoroughly wet, and the whole mass then turned twice to insure proper mixing. It was then put into the trench, and tamped until mortar flushed to the surface. The top surface, after being carefully levelled, and built to the proper grade, was allowed to stand twenty-four hours before receiving the masonry.

Towards the close of the work, stone was substituted for concrete, in order to gain time, and also to leave the shoring undisturbed until the masonry could be immediately put in place. For this large flat stones were used, having an area not less than 12 square feet, nor less than 12 inches thick, firmly bedded in the clay, and all joints well bonded and grouted with cement mortar.

ABUTMENT WALLS.

The abutment walls were built of range ashlar, to the dimensions shown in Fig. 2. The coping projects 2 inches beyond the line of the wall, and extends the full width in one piece. The specifications covering this work were: the masonry must be laid in horizontal courses, having parallel beds and vertical joints on the face, with no stone less than 9 inches in thickness, well bonded and levelled, and laid in good cement mortar. At least one-third of the stone in the face to be headers, evenly distributed throughout the wall; stone in the face-work to be not less than three feet in length, nor less than one foot six inches in width, and every stone to have a bond of at least eight inches with the underlying course, and no mortar joint to exceed three-quarters of an inch in thickness. The backing to be of good-sized, well-shaped stones, laid on their natural bed, and carried up at the same time as the face-work. All stones must be laid to break joints, and thoroughly bond the wall in all directions.

In the walls, every 200 feet apart, spaced alternately on each side, are manholes to provide for the safety of the workmen while trains are passing. These are built capable of holding five men.

For building the abutment walls a travelling derrick was first used. A heavy car was built and mounted on ordinary car wheels, spaced to run on a track of 13 feet 9 inches gauge. At each corner of the rear end was mounted an ordinary stiff leg derrick, firmly secured to the car The framework consisted of two longitudinal stringers on each side, 4 by 14 inches, 20 feet long, spaced 6 inches apart, between which the car wheels rested, while in the centre were three stringers, 6 by 12 inches, spaced evenly between the outsides. Across the ends were firmly framed into the longitudinal stringers two pieces 12 by 14 inches, 15 feet long, and at 7 feet from the outside were two pieces 6 by 8 inches, passing across under the longitudinal framing, and bolted through the top. Passing under these and through the end framing were four ⅞-inch truss rods,

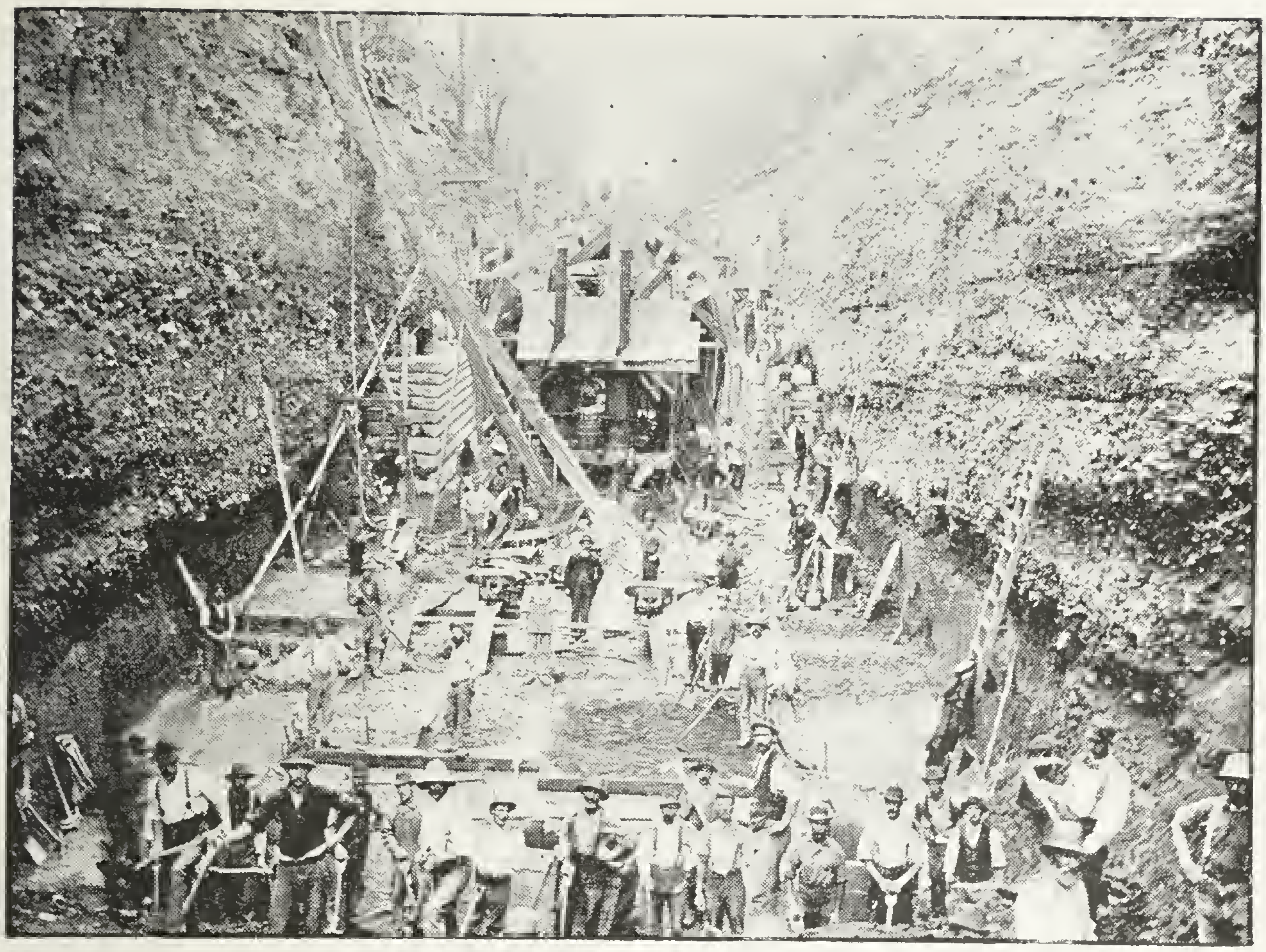


Fig. 3

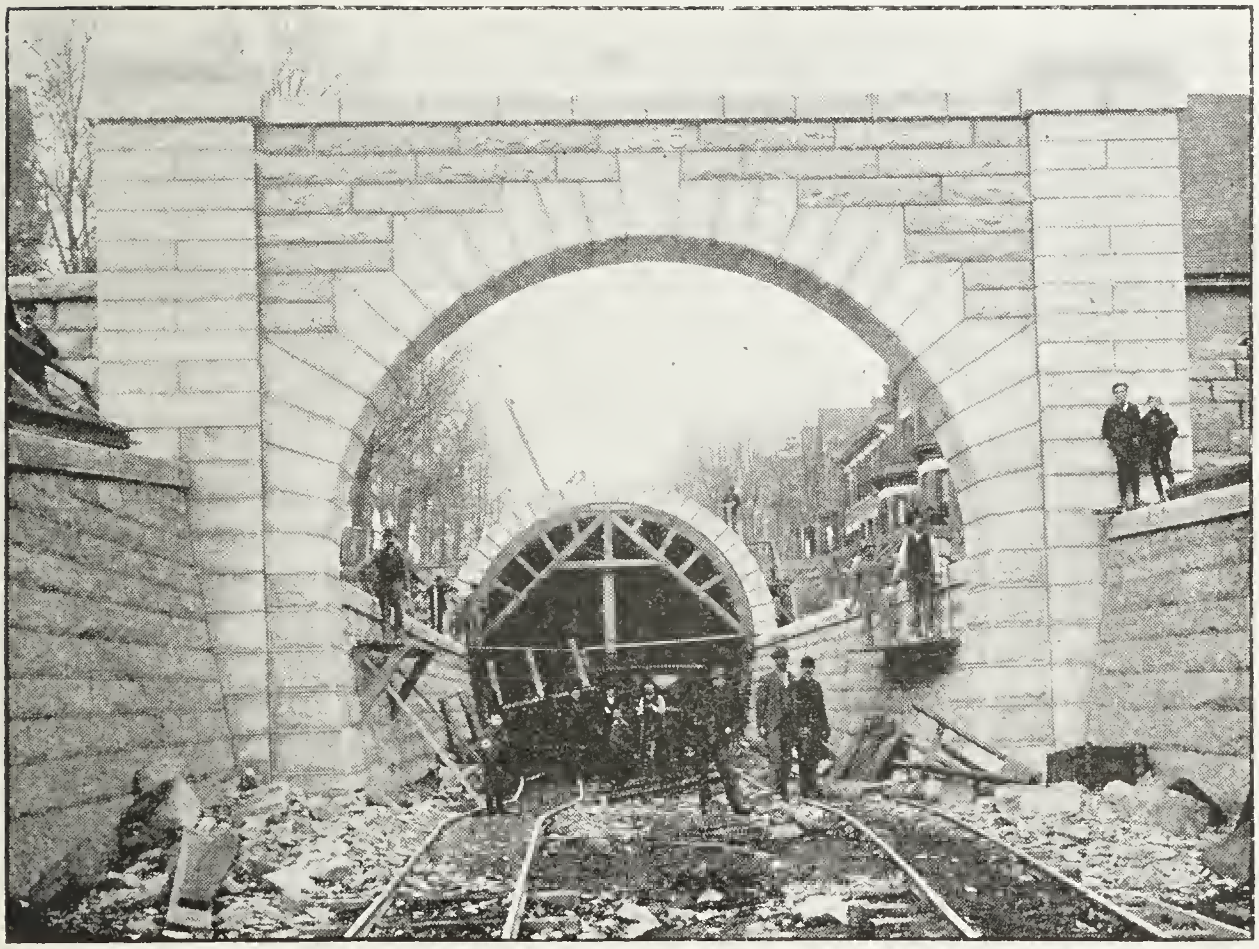


Fig. 4

securely fastened, the whole covered with a 3-inch floor. The principal dimensions of the derricks were: mast, 12 by 12 inches, by 14 feet; boom, 10 by 10 inches, by 20 feet; and stiff legs 8 by 10 inches, by 17 feet; fall and boom ropes ⅞ inch steel cable. Power was furnished by two double drum hoisting engines, 14 horse power each, mounted on the front of the car. This derrick proved very satisfactory for the work in hand, having a quick action and being easily operated.

Building was begun at the east end, and for the first two hundred feet the stone was delivered to the derrick in wagons, but afterwards it was run in on stone cars, a track being laid along each side of the tunnel, using the derrick car-track for the inside rails. The stone was delivered by wagons at Charles street, where it was sorted and run in as required. In this way both abutment walls were carried on together, a gang of masons working independently on each wall.

The travelling derrick was employed up to midway between Bay and Caroline streets, and from the west portal to Hess street; between these two points the shoring and operating of trains prevented its further use. The walls in this section were built by derricks, similar to those used in excavating, erected on each bank. Each derrick had a reach of sixty feet, and was repeatedly moved along the bank as the walls advanced. This method of building was necessarily slow, as the fall blocks had to be operated through 30 to 40 feet of bracing, ofttimes requiring to be repeatedly raised to the top and lowered again in another pocket before the stone was placed in position. The sand and cement were sent down in shutes and mixed below, water being supplied from the city water service; latterly, when the cold weather began, the mortar was made above, and sent down as required. Fig. 3 shows the shutes in position and methods of working.

PORTALS.

These were built of first-class masonry, hammer dressed, and laid in Portland cement, with joints not greater than ¼ inch. The design, as shown in Fig. 4, fully illustrates the work.

BRICK ARCH.

The arch is semicircular, and built of No. 1 selected hard burnt brick, five rows thick, laid on edge. The dimensions, as shown in Fig. 2, are: radius 13 feet 3 inches, with thickness of shell 22 inches. The brick was built over centres set up five feet apart, resting on a six by six inch stringer, placed against the face of the coping, which was supported by posts resting on the foundations. The centres were lined up by two maple wedges placed under each end, and cut so that when placed together the outer sides were parallel. To facilitate easy removal the centres were made in two parts, after the fashion of a king-post truss, and firmly bolted together. When ready to erect, a platform was built level with the top of the coping, the centres bolted together on that and raised to place. When ready to be taken down the platform was re-erected, the centres lowered down, unfastened, and carried along to where again required. A pine lagging 2 inches thick, placed closely together and lightly fastened, formed the covering.

The arch was built in from 25 to 100 feet sections, depending on the length of the abutment wall ready. To more firmly bind the different sections together, the outer end, in each case, was reached back from the springing line to within 3 or 4 feet of the centre, which part was finished square across. Both sides were carried up at the same time, and care was taken that they should be exactly parallel. No special provision was made for keying the arch other than that the key now was selected to fit tight and snug. As soon as the spandril walls were built, the centres were struck, and the arch allowed to take its permanent set; the deflecting under a maximum load of 2,800 pounds per square foot not exceeding ⅛ inch

Before going into the arch all brick was thoroughly wet. This was done by having vats made 12 feet square and 1 foot deep, filled with water, in which the brick was allowed to soak. At first they were continuously put in and taken out of the vat, a process which was not entirely satisfactory. The workmen's hands, through continuously handling the brick in the cold water, became chafed and sore, and, unless watched closely, they were apt to send down brick scarcely wet. This difficulty was overcome by having frames made holding from 30 to 50 brick. In these the dry brick was placed and set into the soaking vat. After remaining in the water a sufficient length of time the frames were lifted out, emptied, and refilled again with dry brick. In this way every brick was evenly saturated, and the workmen were able to keep their hands comparatively dry. In laying the brick, care was taken that all dirt was removed from the lagging and from between the rings, also that all joints were properly cemented and grout poured into all openings until flushed. The several rings were fitted closely together, but not cemented other than what adhered between the joints of the brick.

SPANDRIL WALLS.

As shown in Fig. 2, the spandril wall is built out flush with the back of the abutment wall, and carried up 7 feet 6 inches, with a total batter of 9 inches, from which point the top is finished tangent to the arch. The stone was sent down in shutes, and laid by hand, as derricks could not be conveniently worked. The top surface was covered with a heavy coat of mortar, thick enough to cover all projecting points of the stone and secure a flat surface to the outer covering.

STEEL ARCH.

To carry Park street over the tunnel, it was necessary to grade up the north and south approaches for a considerable distance on each side. To make this grade as flat as possible, the outside of the arch was lowered by using steel instead of continuing the brick up to the portal, and by such gaining 14½ inches. The arch frame was made of 7-inch **T** beams, 25 pounds per foot, bent to the proper radius, and spaced 3 feet centres, the lower ends secured in pockets 2 feet deep, cut in stonework. Each rib was in two pieces, fastened at the top by two splice bars, 18 by 5 by ¾ inch. Extending longitudinally between the ribs, and spaced 3 feet apart, were 3 by 3 inch **T**s, weighing 7 pounds per foot, and firmly riveted at the ends, forming panels 3 feet square, which were covered with ¼-inch buckle plates, raised in the centre 1½ inches, and fastened to the framework by ½-inch rivets, spaced 5 inches apart.

The steel work was shipped from the shops in half sections, two panels long, and ready for erection, thus reducing the field riveting to every third panel, besides the splice plates. All the steel received two coats of graphite paint, one before and one after erection, while around the edges of the buckle plates and joints was put a coating of pure asphalt; the whole was then covered with cement to the depth of one inch above the top of the ribs. The spandril wall was built and otherwise finished over the arch similar to that on the brickwork.

ASPHALT COVERING AND BACK FILLING.

The outside of the arch and spandril wall was protected by a covering of asphalt one inch thick. A coating of tar was first applied to the brick, after which the asphalt mixture, similar to that used in street paving, was applied and firmly rolled. Over this was spread a coat of pure asphaltum, the whole forming an impervious covering to water, and keeping the arch dry on the inside. When this covering was complete the earth was filled back over the arch, care being taken that all pockets behind the spandril walls were properly filled, and rammed solid, and the street restored to its original surface. With the exception of what was excavated by the cable conveyor, all back filling was done by wagons, using the material taken out of the cut. Of this there was not enough left to fill up the street, and some 12,000 to 15,000 yards had to be borrowed to complete the work.

CEMENT.

The specifications called for a cement equal in quality to the finest Louisville brand, and subject to the standard specifications of the American Society of Civil Engineers.

The abutment and retaining walls were built with a natural cement, made at Queenston. This was a slow-setting cement, requiring from five to eight days to harden in the wall, at the end of which time it possessed a moderately high tensile strength.

The brick arch and foundations were laid in Portland cement, the Samson brand, manufactured by the Owen Sound Cement Company, being used, which gave uniformly good results.

The following is a series of tests of the later cement made by Mr. C. H. C. Wright, of the School of Practical Science, covering the time which it was used on the work:

DATE.	Residue on No. 100 Sieve.	Residue on No. 50 Sieve.	Specific Gravity.	Hot Test. Pats immersed 48 hrs. in water at 115° temp.	Tensile strength, 1 day in air, 6 days in water, average of 10 bricks broken.
1895.					
March 11....	12.3 12.7	1.9 1.8	3.098	Sound	384
April 25...........	17.5 17.6	2.0	3. 10	“	531
July 16.	20.5 20.4	2.2 2.1	3. 10	“	464
August 1...	22.0 21.8	3.3 3.0	3. 11	“	426
September 28......	22.1 21.5	9.8 9.5	3. 10	“	478
November 14......	23.1 22.0	10.0 9.8	3. 09	“	465

PROVISIONS FOR BUILDING MASONRY IN FREEZING WEATHER.

In order to carry on the work efficiently in frosty weather, provisions were made for heating the mortar and keeping the stone free from ice and snow. For heating the sand, long iron pipes, about eighteen inches in diameter, were laid on the ground and the sand filled around on the outside, while a fire was kept constantly burning in the pipe. Water was heated in large kettles, and the mortar mixed in small quantities as required for immediate use. The temperature of the mortar when newly made varied from 90 to 100 degrees, and, if kept in a compact form, would retain that temperature until ready for use. During extremely cold weather salt was mixed with the water to form a weak brine, and also was sprinkled over the bed of the stone. For removing ice and snow from the material going in the walls steam was applied through a hose, cleaning the stone and warming the surface to some extent. For first-class masonry, in addition to these precautions, the stone was heated, previous to going in the wall, by hanging it over a fire for a short time, taking care that no injury was done by the smoke or excessive heat. On the brickwork the same precautions were taken, and all tempering and grouting was done with hot water.

DRAINAGE.

This very important item in all underground work cannot receive too careful attention, for on it depends, to a great extent, the durability of the superstructure.

In the present case the manner of treatment and disposal of the water was much easier than is often met with.

With the exception of two places on the work, the water caused no serious trouble, though more or less had to be contended with all along. During construction wells were dug at convenient points as the excavation progressed, and all water drained into these, from where it was pumped up into the city sewers, the ordinary direct-acting plunger pump being the type used. These were placed in the bottom of the cut, and steam supplied from the hoisting engine on the bank.

Just west of the portal, where the floor of the tunnel passed into the quicksand, a retaining wall of concrete was put in, reaching across the bottom, and connected with the foundations on either side. This extended down to the clay, and prevented all water held in the quicksand on the upper side from passing beyond this point, it being here intercepted and led into the side drains, thus keeping the sub-grade, which for the next 200 feet beyond this was quicksand, dry and firm.

For draining behind the walls 3-inch tile was laid along the top of the foundation footing, and every 100 feet apart weepers of the same size were put in flush with the top of the concrete, leading through the walls into the tunnel ; all joints being carefully covered with broken stone to allow the water easy entrance into the pipe. Along the inside of the tunnel, on both sides, were laid 8-inch vitrified pipes, extending the full length, and discharging into open drains at the west portal. Catch basins were put in at the east portal and Charles street to collect the surface water gathering in the east approach, the former connecting with the tunnel drainage and the latter with Charles street sewer.

VENTILATION.

No special provision is made for ventilation other than the natural draft through from the ends, and, under ordinary conditions, the tunnel will clear itself from smoke and gases in from twenty to forty minutes.

QUANTITIES AND COST.

From the limited time given to complete the tunnel, the work was not carried on so economically as it otherwise would have been had the time limit been twelve instead of six months. No expense was spared in providing plant or labor, and everything was done to push the work ahead. The plant in operation on the work consisted of two steam shovels, with the necessary trains to move the material, ten steam derricks, three horse power derricks, and a cable conveyor, besides other plant necessary for the work. Excavation was carried on night and day until complete, and, at times, masonry was also built by night shifts. The excavation was practically finished by December 28th, the tracks connected through the tunnel, and the Government inspection made of the road on December 30th, immediately after which a regular train service was established, thus complying with the spirit of the by-law.

The following tables give the quantities in the different parts of the tunnel :

Excavation in approaches	163,000	cubic yards.
" tunnel	98,000	"
Back filling over tunnel	42,000	"
Concrete laid	2,952	"
Masonry, 1st class	317	"
" 2nd class	8,193	"
" 3rd class	519	"
Spandril wall, 3rd class	4,893	"
Brick arch	5,366	"
Asphalt covering	72,000	square feet.
Steel arch	66,133	pounds

or 829 pounds per lineal foot of arch.

For masonry, asphalt covering, and drains, the tunnel cost $87.00 per lineal foot. This does not include the portals, excavation, back filling, or shoring, which would bring the total cost about $120.00 per foot.

Comparing the cost of the steel with the brick arch, the former, including the concrete covering and spandril walls, exceeded the cost of the brick arch and spandril walls by 33 per cent.

The following table gives the percentage of cement used, and cost of laying one cubic yard of the different classes of masonry.

	Cement used per cubic yard of wall built.	Cost of building one cubic yard of wall.
Abutment walls, 2nd class masonry..	0.55 bbls.	$1.32
Spandril walls, 3rd class masonry....	0.80 "	1.85
Brick arch, masonry...............	0.95 "	1.95
Concrete.........................	1.11 "	0.95

After the travelling derrick was abandoned, and the abutment walls built by derricks on the bank, together with extremely wet and cold weather existing under the latter conditions, the cost of building increased about 50 per cent., while under the same climatic conditions, when it was necessary to use warm mortar and remove ice and snow from the work, the cost of laying brick increased about 30 per cent. The cost of the spandril wall also increased, under these unfavorable conditions, from 20 to 30 per cent. above that shown in the table.

These quantities and prices in the table are averages covering a period in which the conditions for working were favorable and uniform. The figures given is the actual cost of laying the masonry, which includes the hauling of the material into the tunnel for the abutment walls, and conveying brick, stone, etc., from the surface to the work below; also making and carrying the mortar. No allowance is made for plant further than the expense of operating derricks when used, or of bringing material on the ground.

In this table is given the average amount of masonry laid per day of nine hours, per mason, under the same conditions as applying to the previous table.

Abutment walls, 2nd class masonry.......	6.7 cubic yards.
Spandril " 3rd "	3.3 "
Brick arch............................	2.2 "

Allowing 485 bricks per cubic yard of arch built.

The abutment walls were built by gangs of four masons and foreman to each derrick, which the above table refers to.

In laying the concrete it was found that 52 barrels of cement, 36 cubic yards of broken stone, and 19 cubic yards of sand laid 45 cubic yards of concrete in the wall.

The tunnel was designed under the supervision of Mr. E. B. Wingate, chief engineer of the Toronto, Hamilton & Buffalo Railway Company, who are owners of the tunnel; and the work was carried on under the care of Mr. P. Mogenseu, divisional engineer on the works, and the writer as assistant divisional engineer. One contract covered the whole work, from the east approach to Locke street, and was successfully carried out by Mr. A. Onderdonk, contractor.

Under the direction of Mr. Doheny, superintendent of construction, and associated with him Mr. M. R. Northway, the contractor's engineer, the work was prosecuted with unceasing vigor from start to finish.

Though the above work presented no special engineering difficulties, the locality and conditions under which it was constructed, as well as the short time allowed for completion, make it worthy of mention in the annals of modern railroad construction.

THE PENDULUM

By A. M. Scott, '96, Arts.

HISTORICAL SKETCH OF THE PENDULUM, WITH ITS APPLICATIONS IN PHYSICS.

The history of the pendulum begins in 1589 with the discovery, by Galileo, of the isochronous nature of the small oscillations of any swinging body. From this humble beginning, first due to crude observations on a swaying chandelier, there has been an almost continuous progress up to the present ; eminent physicists have given months and years to careful experimenting ; noted mathematicians have applied themselves to the solutions of problems which arose ; great attention has been given to the detection and avoidance of errors, and the ingenuity of scientists, no less than the skill of machinists, has been taxed to produce instruments perfect in every detail, until now the pendulum has become indispensable as a mechanical appliance, while the exact determination of the length of the second's pendulum, with its variations for different places, was never of more importance than to-day by reason of its numerous applications in the field of science. It is not the purpose of the present paper to follow the steps in the development of the pendulum in exact chronological order, but rather to deal with the subject by topics : first, the successive forms which the pendulum of experiment has taken ; second, the various corrections found necessary ; and, last, the physical applications which have been made of the pendulum.

I. After Galileo, who established the principal laws of motion of the pendulum in 1629, the next important discovery is due to P. Mersenne, who, in 1646, submitted to geometers the problem of finding the centre of oscillation, or, as he termed it, the "centre d'agitation ou de balancement" of an oscillating body, the existence of which he had before proved by experiment. The finding of this centre meant the determination of the simple equivalent pendulum; but though Descartes and Cavendish, with others, joined Mersenne in his investigations, the solution of the problem was not found until given by Huygens in his "Horologium Oscillatorium," 1673; the application of this solution by the three Bernoullis to the pendulums then in use made it possible, by 1726, to calculate exactly the length of the simple equivalent pendulum, allowance being made even for the weight of the suspending thread.

By Mersenne and Descartes the simple pendulum was considered as "un plomb suspendu à un filet"; later, the discovery of the centre of oscillation and the tendency of particles above or below this to change the rate of motion, together with the effects due to the weight of the thread, have caused it to be defined as "a particle of matter suspended by a right line devoid of weight, and oscillating by the force of gravity about a fixed point, called the point of suspension." It is now known to be an ideal instrument which can never be realized in actual experiment, but first notions fixed the form of the pendulum for many years. As used by all physicists and astronomers till the end of the eighteenth century, it consisted of a ball of lead or copper about an inch in diameter suspended by a thread, usually of pite or aloes, which was held at its upper extremity between firmly fixed metallic jaws. Godin and Bradley, in their experiments from 1743 to 1749, introduced the use of a metallic thread, and joined it to a knife-edge which rested on a fixed plane and became the centre of suspension for the pendulum. Bouguer, about the same time, tried the use of two truncated cones joined by their larger bases instead of a spherical ball, but this was not generally adopted.

The next improvement was suggested by P. Boscovich in his work on "Optics and Astronomy," published in 1785, one chapter of which was headed: "De determinatione longitudinis Penduli oscillantis ad singula minuta secunda temporis medii." Though a purely theoretic paper, this was very carefully prepared, and is important as showing the progress made in pendulum study at that time, and also on account of the great number of ingenious details and corrections therein suggested, many of which were not adopted until years later; other references may be made to it in the course of this sketch. He thought that the knife-edge could be so constructed that its oscillations would not affect those of the ball and suspending thread. This was found difficult to do, but Borda and Cassini, in their memorable experiment in 1810, to determine the length of the second's pendulum at Paris, attached a screw to the upper part of the knife-edge perpendicular to its length; along this a small metal button could be raised or lowered, and served as a regulator by means of which the time of oscillation was made the same for the knife-edge alone, resting on the plane surface, as when the ball and thread of the pendulum were attached. " Ce synchronisme une fois établi, il est clair que le mouvement du pendule, n'etant pas contrarié par celui du couteau, devait être le même que si la masse du couteau et de sa mouture avait ête pour ainsi dire nulle," writes Borda ; this was confirmed by experiment.

The pendulum used by these men consisted of a platinum ball about 1⅓ inches in diameter, suspended by a finely drawn iron wire, which was fastened to the knife-edge just referred to ; platinum was chosen for the ball on account of its great density, and iron wire preferred for its strength, also because it offered less surface to the resistance of the air than silk or vegetable fibre threads. To correct the error that might arise from irregularities in the shape of the ball, or inequalities in density, the wire was joined to a small cap consisting of a segment of a spherical shell, which had the same radius as the ball and could be attached at any point. On account of the extreme care taken in their experiments, and the degree of perfection to which they brought the so-called simple pendulum, Borda and Cassini seemed to leave nothing for their successors except to repeat the same methods, unless some new form were devised for the instrument.

In the meantime, Chevalier de Prony, in 1792, and more definitely in 1800, had set forth the advantages to be gained by the use of a rigid pendulum of considerable mass, which might oscillate about several parallel axes, all in the same plane, passing through the centre of gravity of the instrument. These were as follows :

" 1°. De dispenser absolument d'avoir égard à la forme du corps ;

" 2°. De pouvoir employer une masse d'un assez grand poids pour qu'elle oscillât, sans interruption, pendant tout le temps qui s'écoulerait entre deux passages consécutifs d'une étoile par un même vertical.

" 3°. Enfin, de faire les expériences avec un corps de forme invariable, de la plus grand solidité, dont la conservation indéfinie et le transpor n'offrent aucune difficulté, et sur lequel on peut repétér, à une époque quelconque et dans les lieux différents, des expériences parfaitement comparable et des mesures absolument indentiques avec celles qui ont servi à une détermination primitive."

From the times of oscillation about three axes, the moment of inertia of the system about the centre of gravity could be calculated; thence, with the aid of the distances of the axes of suspension from the centre of gravity, the lengths of three simple equivalent pendulums determined. But though the merit of this method was recognized by scholars, and a simpler form of the instrument devised by Bohnenberger in 1811, it was viewed with disfavor by advocates of Borda's methods, and did not come into use. It was not till the principle of the reversibility of the centres of suspension and oscillation, first due to Huygens, was applied to the pendulum by Captain Kater, in 1817, that the reversible pendulum assumed a practicable form, with two fixed axes of suspension parallel to each other, and a system of movable weights, to be adjusted so that when either axis was the centre of suspension the other would become the centre of oscillation.

On account of the absence of any very definite mathematical principles governing the adjustment of the weights of the Kater's pendulum, which process, as we can testify, is necessarily long, and may become tedious, the ball and thread continued to be used until the time of Bessel's experiments, in 1826, to test Laplace's theory of the influence of the form of the knife-edge on the true length of the pendulum. Laplace, in studying Borda's pendulum in 1816, maintained that the knife-edge was not a true geometrical angle, but a cylindrical surface, which, during the oscillation, rolled upon the plane supporting it; and, therefore, that the distance measured from the knife-edge to the centre of the ball, to determine the length of the pendulum, must be increased by the radius of this cylinder, to get the true length. Also, the centre of suspension, being raised slightly above the plane of support, constantly changes in position if the surface of the knife-edge is not truly circular, and thus, theoretically, a disturbing influence on the duration of an oscillation, and the length of the simple equivalent pendulum, is introduced. Bessel's numerous experiments verified this hypothesis, and led him to conclude that it is impossible to measure exactly the length of the simple pendulum by the use of a single knife-edge, owing to the error introduced by the cylindrical form, whose radius of curvature is indeterminate, from its very small size. In addition to this, the experiments of Baily, in 1832, to find the necessary correction for reduction to a vacuum, along with the calculations of Stokes, showed that the resistance of the air to the suspended thread increased as the thread became finer, thus helping to make the simple pendulum a very complex instrument.

For these reasons, attention was then turned to the perfecting of the reversible pendulum, chiefly to get rid of the errors arising from the resistance of the air, and from the form of the knife-edges, both of which are present to some extent in the Kater's pendulum. On account of its unsymmetrical form, the resistance of the air is different in the two positions, and when the adjustment has been made so that the oscillations in air are of equal duration for both positions they will not be so in a vacuum; further, no allowance is made, or can be made, for differences in the form of the suspending knife-edges, which, though they may be nearly so, are not identical. Bessel, in a paper entitled, "Construction d'un pendule symétrique à axes reciproques," 1849, described an instrument afterwards constructed by Repsold, and now known by his name; in this were embodied the results of Bessel's thorough and extensive investigations into the different sources of error. It was made perfectly symmetrical in form, that the influence of the air should be the same for both positions; and the knife-edges were so arranged that they might be exchanged, in order to eliminate the error arising from their differences of form, that is, from their unknown "cylindricité," as it is called. After a long mathematical calculation, Bessel's conclusion is: "Mais il y a un moyen très simple d'eliminer complètement l'influence de la cylindricité: on dispose le pendule de telle sorte que l'on puisse échanger entre eux les deux couteaux, et l'on fait les expériences avant et après cette permutation. Il en résulte deux erreurs égales et de sens opposé qui disparaissent dans la moyenne." The account of an experiment and calculation to determine the height of the centre of suspension above the plane of support is given in the same paper, and summed up as follows: "Mais on voit, d'apres cela, que cette expérience ne fournit aucun motif de penser qu'un couteau aussi admirablement travaillé que celui de M. Repsold, dont il a été fait usage dans ces recherches, donne le centre du mouvement sensiblement trop bas."

Repsold's pendulum was first employed in 1866, at Geneva, and, though the mistake was made in not having a solid support for it in the first experiments, it was adopted the following year by the International Geodetic Association, and has since been generally considered among European scientists as the best instrument for the absolute determination of gravity. The report of this Association for 1883 gives the following conclusions, based on previous observations:

"1°. Le Pendule à reversion de Bessel possède à un très haut degré tout les qualitiés requises pour les déterminations absolues de la pesanteur, si l'on fait osciller deux Pendules d'un poids essentiellement différent sur le même support.

"2°. Il faut non seulement employer les mêmes couteaux pour les deux Pendules, mais ces couteaux doivent pouvoir être échangés pour chaque Pendule. Les couteaux en agate sont préférables à ceux en acier.

"3°. Il faut faire les observations dans des localitiés (locaux) d'une temperature presque constant; l'emploi du vide n'est pas recommandable.

"4°. Les durées d'oscillation doivent être observées pour les deux positions du Pendule dans les mêmes limites d'amplitude."

These do not show much change from Bessel's results, except the use of the two pendulums to correct the error arising from the flexure of the support. In the experiments performed under the direction of the United States Coast and Geodetic Survey during the last twenty years or more, the Kater's pendulum has been used for absolute measurements, and both this and Repsold's are recognized as giving very accurate results.

A word must yet be said of the invariable pendulums used by Kater in 1819, and by many since his time, for making differential measurements. They had only one axis of suspension, the knife-edge and the weight were securely fastened to the rod ; then the period of the pendulum at various places was compared with its period at a certain base station, where, by means of a reversible pendulum, an absolute measurement had been made. Most of the recent experiments have been made with some form of invariable pendulum ; a very fine one, prepared under the direction of T. C. Mendenhall, Superintendent of the United States Coast and Geodetic Survey, for use in his work, is described in an appendix to the report of the survey for 1891. It was made one-fourth the usual length, and beat half-seconds, a form used successfully in 1883-4, by Von Sterneck, in the mines of Pribram and Bohemia, and was allowed to swing in a receiver, which could be exhausted of air ; besides three different pendulums which could be used successively, the outfit included a dummy with a thermometer attached, to be placed in the receiver for the accurate determination of the temperature. This instrument possessed the merit of being convenient to carry, and so easily adjusted that an observation could be taken in a few hours. Many forms of invariable pendulums have been constructed ; one prepared for Commandant Defforges, in France, of symmetrical form, with reciprocal axes, and knife-edges that could be exchanged, gives probably the most correct form in theory, though Major Herschel, of England, strongly objected to the use of the term " invariable " as applied to such instruments.

The method of determining exactly the duration of an oscillation, or the number of oscillations made by a pendulum in a given time, has always been by comparison with the pendulum of a clock which beat seconds of mean time. In the first attempts, the pendulum of experiment was placed before the clock pendulum, so that both could be observed easily ; the former was made to begin its oscillation at the same time as the latter, and in the same direction ; the observer then looked from time to time to see if they continued to oscillate together ; if not, the suspending thread of the experiment pendulum was made shorter or longer, as it went slower or faster than the other, and this process of adjustment was kept up until the two pendulums continued to oscillate exactly together. This method was used and described by the abbot Picard, 1669, and by J. D. Cassini, 1681, and was followed by others till 1735, when M. de Mairan, who was making some experiments at Paris with the pendulum to obtain results for comparison with those to be obtained from similar experiments at the equator, devised a new method, which he designated "la méthode des concours."

The pendulum of experiment having been placed before the other, the concurrence took place when both at the same instant reached the limit of an oscillation on the same side of the vertical; the interval of time between two successive concurrences, expressed in seconds, gave the number of oscillations of the clock pendulum in that time, and the number made by the other was two more or two less, as it went faster or slower. From this result the number of oscillations made by the experiment pendulum in twenty-four hours could be easily calculated.

Mairan's method was defective, because the decreasing amplitude of the arc of vibration brought the thread of the experiment pendulum to a different position for each concurrence, and, further, because the concurrence was noted when both pendulums were at a standstill, a difficult thing to decide accurately, as their rates of motion were, in general, different. Bouguer and La Condamine used a method between this and Picard's; the pendulum was made to oscillate nearly in unison with the clock, so that they would swing for a length of time together; then the observer determined as accurately as possible, when a complete oscillation had been gained, by the aid of a scale attached to the clock, and divided into twelfths. Godin and Bradley used an eye-and-ear method, noting when the thread of the pendulum passed the vertical position exactly in coincidence with the ticks of the clock; the method of coincidences, as used by Borda, Kater, and many others during the present century, was explained in full detail by Boscovich, 1785, in his work already referred to. The pendulum of experiment was to be placed exactly in front of the clock pendulum, both made to oscillate, and some means provided to determine when both passed the vertical position at the same instant. Observations were made through a telescope to decide, with Borda, when a bright spot on the clock pendulum, made by the intersection of two white lines, disappeared behind a screen at the same instant as the suspending wire of the other; and with Kater, when a similar spot was hidden by the tail of the experiment pendulum, all observations being taken at the vertical position of both pendulums.

Various applications of the same principles have been made by experimenters to ensure greater accuracy in this method, the principal changes being due to the use of mirrors and lenses attached to the pendulums, and electric batteries with a clock or chronometer in circuit, to register the time on a chronograph, or to emit flashes of light at regular intervals. Lieut.-Col. Herschel used a small disc fastened to the clock pendulum, having, instead of the two intersecting lines, a ray of light focussed on it by a lens, and reflected into the telescope; this made a very bright spot, whose appearance or disappearance could be easily noted, and gave very satisfactory results.

In the report of the United States Coast and Geodetic Survey for 1881, C. S. Peirce describes a method which includes a scale divided into half millimetres, fixed on the clock pendulum, a lens attached to the other pendulum, an adjustable lens between them, and an eye-piece to view the image of the scale as given by the two former; this is capable of fine adjustment, and accuracy is claimed to the thousandth part of a second in finding the length of an interval.

In the report of the same survey for 1891, in connection with the invariable pendulums already mentioned, Prof. Mendenhall gives the full description of the method he used. By means of a couple of shutters, regulated by electrical connection with the chronometer, a flash of light from within a closed box was sent out at regular intervals against a mirror attached to the pendulum. If the flash came when the pendulum was in its lowest position, it was reflected into the telescope, but not at other times. As the flash was sent out every second, this was equivalent to finding the coincidences between the pendulum of experiment and a second's pendulum, the appearance of the flashes in the telescope showing the times of successive coincidences.

This same person had already used a new and interesting way of finding the time of an oscillation in his work in Tokio in 1880. A "trip-hammer" of very little weight could be introduced at any instant under the pendulum, so that when the lowest point was next reached the hammer was thrown, and an electric circuit broken; the instant of the break was recorded on a chronograph, which registered seconds. The "trip-hammer" was introduced at the beginning and end of the period of observation, so did not interfere with the vibrations between, and the time of an oscillation could be found by counting the whole number made in the time as registered. This method gave a very accurate determination of the time, several successive swings showing a variation of only the sixty-thousandth part of a second in the time for a number of oscillations, lasting about thirty minutes; it comes nearest to the ideal method in this respect, that the time is registered automatically, and is, therefore, not affected by any error in the observer's judgment.

II. Although Galileo established the laws of motion of the pendulum, it seems to have been, as one author remarks, more the result of intuitive genius than of accurate observations, for he failed to perceive the difference in duration of the oscillations, due to the amplitude of the arc, though his observations extended to arcs of ninety degrees on each side of the vertical. The abbot Picard, in his experiments about 1669, noticed that the duration of an oscillation was greater for a large arc than a small one, and tried to correct the error introduced through the diminishing amplitude by observing only very small oscillations, in which he was followed by La Condamine, and also by Bradley, 1743. In the theory of the pendulum, as given by Huygens, 1673, and by Newton, 1683, the oscillations are supposed to be executed in the arc of a cycloid, in which case no account need be taken of the amplitude. Bouguer made a number of experiments to determine the effect of the varying amplitude, and, besides finding the duration of the first vibrations, in an arc of more than three degrees, clearly longer than when the arc was small, he also discovered that the amplitudes, taken at equal intervals of time, showed a decrease in geometric progression. But the formula for the reduction of the time of an oscillation to that in an infinitesimal arc was first due to Daniel Bernoulli, who published it in 1747.

Neglected for a number of years as unnecessary, this correction was not used until recommended by Boscovich, who explained its necessity, and put it in the form of a geometric series, based on the law of the decrease of the amplitude in geometric progression, as stated by Bouguer. By Borda, through whom most of the suggestions of Boscovich regarding the pendulum found expression in actual experiment, this was further simplified, and the formula given in the form still used; though some doubt was cast on the correctness of this by Captain Sabine, a proof was given by Mathieu, in 1826, and it has been generally accepted since.

The effect of the fluid medium in which a pendulum oscillates was first studied by Newton, who caused a pendulum, ten and a half feet long, to oscillate in air, and also in water, first with a ball of wood, then with one of lead, and a similar one with a ball of iron to oscillate in water and in mercury. The result he arrived at was that the amplitude of the oscillation was affected by the resistance of the air or other fluid, but that there was no perceptible influence on the duration, the loss of motion by the pendulum during the upward part of its swing being compensated by its gain during the downward part. Some indications are found, however, of a correction by Newton to the length of the second's pendulum "ob pondus aeris"; the necessity for the correction was afterwards shown by Bouguer, and a method described to determine accurately its amount, from which it is sometimes called Bouguer's correction.

The error it is intended to overcome results from the loss of weight of the pendulum, due to the mass of air it displaces, and is spoken of by Kater as the error due to the "buoyancy" of the atmosphere, to correct which it is necessary to know the ratio of the weight of air displaced, to the weight of the pendulum. Bouguer determined the relative weight of the air to mercury by finding the height through which a barometer must be raised that the mercury should fall one line; then by comparing the specific gravity of the pendulum with that of the mercury, the relative weight of the pendulum to the air displaced was found. Kater made use of the known ratio of the densities of air and water, then found the mean specific gravity of the pendulum, and was able to calculate the ratio of the weight of air displaced to that of the pendulum. "That the number of vibrations in a vacuum might be the same as in air, it is necessary to increase the length of the pendulum in the proportion of this ratio to unity, since the length of the pendulum which oscillates in the same time varies as the intensity of gravity."

This was the only correction generally considered necessary to reduce the time of oscillation to vacuum until Bessel advanced the theory that the mass of air set in motion by a pendulum affects the duration of an oscillation. Similar conclusions had been reached by Buat, in 1786, who ventured to differ from Newton, and wrote concerning him and his experiments: "Il ne s'attacha qu'aux pertes des amplitudes, sans observer la durée des oscillations."

Bessel's argument is as follows: "Si l'on désigne par m la masse du corps qui se meut dans un fluide, par m' celle du fluide qu'il déplace, on a pris, depuis Newton, pour valeur de la force accélératrice qui agit sur le corps

$$\frac{m-m'}{m},$$

et c'est avec cette formule qu'on a toujours réduit les expériences du pendule.

"L'adoption de cette valeur est fondée sur cette hypothèse que la force motrice à laquelle le corps est soumis, et qui est égale à $m-m'$, se repartit sur la massa qui constitue le corps. Mais, en réalité, elle se repartit non seulement sur cette masse, mais aussi sur toutes les particules qui sont mises en mouvement en même temps que le corps ; donc aussi sur les portions du fluide qui sont entraînées ; par suite, le denominateur de la formule qui représents la force acceleratrice est necessairement plus grand que *m*."

After a long and intricate calculation, his conclusion is, in the words of Baily, "that a fluid of very small density surrounding a pendulum has no other influence on the duration of the vibrations than that it diminishes the gravity and increases the moment of inertia. When the increase in the motion of the fluid is proportional to the arc of vibration of the pendulum, this increase of the moment of inertia is very nearly constant ; in all other cases it will depend on the magnitude of the arc." It may be inferred, and has been found, that the amount of the correction for reduction to a vacuum will vary with the length, magnitude, weight, density, and figure of the pendulum, and also, in the case of the reversible pendulum, will not be the same for both positions. Bessel gives a formula to find the length of the pendulum reduced to vacuum :

$$\lambda = \frac{(i^2 + s^2)(m + km')}{s(m - m')}$$

where i is the radius of gyration, s is the distance of the axis of suspension from the centre of gravity of the pendulum, m and m' the masses of the pendulum and of the fluid displaced, and k a constant to be determined by experiments, in which m is made to vary and all other conditions remain the same.

Captain Sabine tested Bessel's theoretical correction in 1829, on a Kater's invariable pendulum, and found it too small. Baily, in 1832, made extended and careful experiments to find the ratio of the new correction for reduction to a vacuum to that before used. He tried many different pendulums, and varied the magnitude, figure, mode of suspension, etc., as much as possible, coming finally to the conclusion "that the amount of the required correction cannot (according to our present knowledge on the subject) be determined by calculations, but must in every case be determined by actual experiment."

Baily's experiments made to determine this ratio n, as he called it, corresponding to $1 + k$, where k is Bessel's constant in the formula for reduction, gave values ranging from 1.728 to 2.070 for different pendulums ; Sabine had found a value 1.655 for a Kater's invariable pendulum, and Bessel's formula gave a still smaller value.

C. S. Peirce, who studied the same subject, says in the report of the United States Coast and Geodetic Survey, 1876, that "the presence of the air lengthens the period of oscillation in no less than four distinct ways:

"1°, by its buoyancy;

"2°, by being carried along within enclosed parts;

"3°, by the hydrodynamic effect of its pressure;

"4°, by its viscosity."

"By the viscosity is meant what Stokes terms the index of internal friction, and Maxwell the kinematical viscosity." The account of an experiment to determine the amount of the correction to be applied to a Repsold's pendulum is given in the same paper, and a curve drawn showing its variations for temperature and pressure.

Another correction which has caused some discussion is that for the reduction to the level of the sea. Kater, one of the first to use it, says: "The force of gravity increases in the inverse ratio of the square of the distance to the centre of the earth." Young, in 1819, contended that some allowance should be made for the attraction of the matter above the sea level, and gave a formula to include this; the formula, as well as a fuller discussion, is given in another part of this paper.

Besides these corrections, that for the rate of the time-keeping apparatus is always applied, as well as one for variations in the length of the pendulum due to the changes of temperature; this last is usually determined by experiment. Many minor corrections have been used or investigated by different persons; their necessity in many cases depends on the conditions under which the experiment is performed. A complete list of the corrections to be applied to obtain accurate results was given by C. S. Peirce in 1876. Speaking of the time of an oscillation, he says: "The observed duration has to receive the following corrections:

"1°. The correction for the rate of the time-keeper.

"2°. The correction for amplitude of oscillation.

"3°. The correction for pressure and temperature of the air.

"4°. The correction for expansion of the metal by heat.

"5°. The correction for the slip of the knives.

"6°. The correction for the wear of the knives.

"7°. The correction for inequality of knives.

"8°. The correction for stretching of pendulum by weight of heavy bob when down.

"9°. The correction for the flexure of support.

"10°. The correction for attraction of the sun, moon, and tides.

"11°. The correction for elevation above sea level."

A discussion of each in turn is then given. (See United States Coast and Geodetic Survey, 1876.)

III. The first application of the pendulum arose from the use of the so-called simple pendulum as a measure of time. It was noticed in 1643, by Calignon de Perrins, a gentleman of France, that a pendulum thirty feet long, though left entirely undisturbed, performed each day alternate oscillations corresponding to the ebb and flow of the tides.

This phenomenon, known as reciprocation, was thought to be the proof of a slight mutation in the axis of the earth ; but the most careful experiments by M. Bouguer, P. Ximenes, and Andreas Mayer, about a hundred years later, proved only the existence of air currents, and of unequal expansion at different hours of the day of the walls from which the pendulum was suspended.

Next in order of time, but perhaps first in order of usefulness, came the application of the pendulum to clocks, it being substituted for the older balance now known only as a curiosity. Just within the Porta del Popolo, in the Passeggiata del Monte Pincio, at Rome, there stands yet one of the old-fashioned clocks, kept in motion by a steady stream of water which runs into a bucket and causes one end of the balance to fall at regular intervals.

The introduction of the pendulum marked such a great advance in time-keeping apparatus that the honor of having first used it has been claimed for a number of different persons, Galileo, Huygens, Bürjï, as well as several local clockmakers. Galileo was certainly the first to conceive the idea of constructing a clock with a pendulum, and even gave his son Vincenzo, in 1641, a design for the mechanism of the apparatus ; but both father and son died before it had been carried into execution, and the design was only unearthed after more than two centuries by M. Alberi, who published it among Galileo's works in 1856. Huygens, without any knowledge of the great Italian's design, planned and had constructed, in 1657, the first pendulum clock, and to this noted physicist and astronomer, therefore, properly belongs all the honor of giving to the world this useful application of the pendulum.

The effect of changes in temperature on the rate of the pendulum clock was noticed by Picard in 1669 ; the gridiron compensation pendulum was invented by Harrison in 1725, and the mercury pendulum by Graham in 1726. Oerstedt, in 1809, and Jürgensen, a Danish clockmaker, from 1828 to 1832, studied the effect on the rate of the clock of variations in the density of the air ; various forms of compensating pendulums have been devised from that time to the present, the descriptions of which scarcely come within the sphere of the present paper, though it might be mentioned that a very high degree of accuracy has been attained.

By Newton, in 1686, an entirely different use was made of the pendulum; it became in his hands a means of proving one of the fundamental laws of attraction, viz., that the weight of a body is proportional to its mass, irrespective of the substance composing it; that is, that the force of gravity is not selective.

"Descensus gravium omnium in Terram (dempto saltem inæquali retardatione quæ ex Aeris perexigua resistentia oritur) æqualibus temporibus fieri jamdudum observarunt alii; et accuratissime quidem notare licet æqualitatem temporum in Pendulis."

His experiments were made with two pendulums, eleven feet long, the balls being of the same size and shape, and hollow, so that different materials could be put in them, while the resistance of the air remained constant. "Unam implebam ligno et idem auri pondus suspendebam (quam potui exacte) in alterius centro oscillationis, . . . et paribus oscillationibus juxta positæ ibant una et redibant dintissime." He tried the following different materials: gold, silver, lead, glass, sand, common salt, wood, water, and wheat; and the exactness of the work done may be inferred from his own statement: "In corporibus ejusdem ponderis differentia materiæ, quæ vel minor esset quam pars millesima materiæ totius his experimentis manifeste deprehendi potuit."

Since Newton's time, the pendulum has been recognized as an important instrument in the hands of the physicist on account of the relation between the time of an oscillation, the length of the simple equivalent pendulum, and the force of gravity. This relation is shown by the conclusion reached in Prop. LII., Prob. XXXIV., Book I. of the Principia:

"Itaque oscillationes in globis et cycloidibus omnibus, quibuscunque cum viribus absolutis factæ, sunt in ratione quæ componitur ex subduplicata ratione longitudinis fili directe, et subduplicata ratione distantiæ inter punctum suspensionis et centrum globi inverse, et subduplicata ratione vis absolutæ globis etiam inverse."

Applied to the attraction of the earth on a simple pendulum, this gives the well-known formula:

$$t = \pi \sqrt{\frac{l}{g}}$$

a demonstration of which is ascribed by M. C. Wolf to E. Jacquin, 1861.

The accurate determination of the length of the simple pendulum which beats seconds of mean time has been the cause of a very large number of pendulum experiments. The earlier experimenters, including Huygens, Picard, and many others, considered it an invariable length for all places on the earth's surface, which idea seemed to be confirmed by Picard's experiments in a number of places, extending from Denmark to the south of France.

The object of these men was to establish a system of measures of length with the length of the second's pendulum as the unit, and even when this was known to be variable the project was not given up; it was proposed by some to use the length of the second's pendulum at Paris, by others that at the equator, as the unit. It was not till 1791 that "l'Académie des Sciences," of Paris, decided that the second's pendulum should not be chosen as the unit of length. The reasons given by "les Commissaires" were:

"1.° Que cette longeur repose sur l'adoption d'une unité tout à fait arbitraire, la seconde de temps;

"2.° Que sont adoption fait intervenir dans la détermination de l'unité de longeur deux considérations qui lui sont étrangères, celle du temps et celle de l'intensité de la pesanteur."

Whether the reasons as given were altogether valid or not, it seems certain that much confusion would have been caused among those using the metric system by having a unit so difficult to determine accurately, or so liable to repeated corrections. C. S. Peirce, however, speaks quite decidedly to the contrary: "I will even go so far as to say that a physicist, in any remote station, could ascertain the length of the metre accurately to a one-hundred-thousandth part more safely and easily by experiments with an invariable reversible pendulum than by the transportation of an ordinary metallic bar."

But before it had been decided not to use the length of the second's pendulum as a standard of measurement, new interest in pendulum experiments had been created by the fact that an absolute determination of this length was equivalent to an absolute determination of the acceleration of gravity, which is probably the most wonderful result given to physical science by the pendulum. There has always been a charm about such a work as finding the absolute force of gravity. Major Herschel, in *Nature*, 1880, says: "There is something seductive, it must be admitted, in the conciseness and completeness which attends an absolute determination, as contrasted with the dependence of a differential one."

The first determination of the length of the second's pendulum was made by P. Mersenne, in 1644; the fact that its length is variable was shown experimentally by M. Richer, in 1672; and Newton's famous law of universal gravitation gave the reason for this variation in the fact that the attraction of gravity increases as the distance from the centre of the earth increases. Assuming the earth to be a homogeneous spheroid, whose axis varies continually in length from the equator to the poles, Newton established that "incrementum ponderis pergendo ab Æquatore ad Polos sit quam proxime ut sinus versus latitudinis duplicatæ; vel quod est, ut quadratum sinus reti latitudinis. . . . Gravitas ad Polum sit ad gravitatem sub Æquatore ut 230 ad 229, et excessus gravitatis ad Polum ad gravitatem sub Æquatore ut 1 ad 229." The length of the second's pendulum being proportional to gravity, these results give two formulæ:

$$l_\phi = l_\circ\,(1 + m\sin^2\phi)$$
$$l_\phi = l_{45}(1 - m'\cos^2\phi)$$

where $l_\circ$ = length of second's pendulum at the equator,

l_{45} = length at latitude 45°,

l_ϕ = length at latitude ϕ,

$m = \frac{1}{229} = .00437$,

$m' = \dfrac{\frac{1}{2}m}{1 + \frac{1}{2}m}$.

Clairant showed that the law of the square of the sine of the latitude, as given by Newton, held in the case of homogeneous concentric shells; Laplace, in "Mecanique Celeste," Livre III., established a formula previously given by Clairant for the determination of m:

$$m = \frac{5}{2}\frac{f}{g_0} - \frac{a-b}{b},$$

where f = acceleration of the centrifugal force at the equator due to the earth's rotation;

g_0 = acceleration of gravity at the equator;

a and b = the equatorial and polar semi-axes.

In his "Collection des Memoires relatifs à la Physique," M. C. Wolf gives a table of 23 different values of m, m', and l_0, which have been calculated by various mathematicians from Newton, in 1713, to Helmert in 1884. From these he gets mean values of the three quantities which give Newton's formulæ, as follows:

$$l_\phi = \overset{\text{mm}}{991.000}\,(1 + .00520\sin^2\phi)$$
$$l_\phi = 993.577\,(1 - .00259\cos 2\phi)$$

These give a connection between the latitude of a station and the length of the second's pendulum there, based on an assumption of the mean figure of the earth; and many experiments have been conducted, first, to test the hypothesis; second, to determine the real figure of the earth. A large part of the variation in the value of g, as found experimentally, from that given by the formula was found to be due to the height above the sea level, and in most cases, according to C. S. Peirce, when "the value of gravity upon high lands and mountains is corrected for difference of centrifugal force, and distance from the earth's centre, it is very little greater than at the sea level," as given theoretically.

There were cases, however, which could only be accounted for by the increase of the force of attraction due to the density of the land or mountain on which the observation was made being greater than the mean density of earth. Bouguer had conducted experiments from 1737 to 1740 to determine the variations in the length of the second's pendulum for three different altitudes in Peru. In space free of matter, gravity might be expected to decrease according to the inverse square law starting from the centre of the earth, but was observed to decrease more slowly; this excess of gravity above its value in a free space was thought to be due to the attraction of the matter above the sea level. Bouguer obtained a formula for the value of gravity on a plateau of height h, as compared with that at sea level,

$$g_1 = g\left(1 - \frac{2h}{r} + \frac{3h}{r}\frac{d}{D}\right)$$

where r = radius of the earth.
d = density of plateau.
D = mean density of the earth.
g = value at sea level.

This formula was revived by Young, and applied in 1819 to make a correction to Kater's value of the length of the second's pendulum at London, d being assumed to be 2.5 and D, 5.5. He put it in the form

$$\frac{g - g_1}{g} = \frac{2h}{r}\left(1 - \frac{2}{3}\frac{d}{D}\right)$$

An interesting application was made of this attraction of matter above the sea level to discover the mean density of the earth. M. Carlini, in 1821, determined the value of gravity on Mont Cenis, and used M. Biot's result, taken at Bordeaux, for the length of the second's pendulum, for comparison with his own value. Correcting Biot's result for the latitude of Mont Cenis, and assuming the mountain to be the segment of a sphere 1 mile high with a base 11 miles in diameter, he found D in terms of d.

In 1826, Mr. Airy (afterwards Sir George Airy and Astronomer Royal) thought that this mean density might be determined by observing the difference in the rates of a pendulum at the top and bottom of a mine. After several unsuccessful attempts, the experiment was conducted, in 1854, at the Harton Pit, a coal mine in the county of Durham, England, and a value of 6.565 was found for D when d was assumed equal to 2.5.

Major Von Sterneck tried the same method from 1882 to 1885, in the mines at Pribram, in Bohemia, and Freiberg, in Saxony. His work, though conducted with the greatest possible care, gave values for D ranging from 5.66 to 7.60; d was assumed as 2.75. He attempted to explain this variation only by the hypothesis of an underground variation in density, which could not be determined.

Prof. Mendenhall, in 1880, made determinations of the relative values of gravity at Tokio, and at the summit of Fujiyama, by means of a Kater's pendulum divested of everything but the heavy weight and the corresponding knife-edge. This mountain was chosen from the regularity of its shape, and the result obtained as accurately as can be expected from this method. The value of d was estimated from specimens at 2.12, and D found to be 5.77.

There is considerable uncertainty in the assumption of the mass and density of the matter above sea level, and this, with Airy's view, shared by C. S. Peirce, "that mountains are not additions to a spheroidal earth, but the exposed parts of lighter matter buoyed up," leads to Poynting's conclusion, "that our knowledge of the distribution of the terrestrial matter is not yet sufficiently accurate to enable us to obtain good values of the mean density from the observed attraction of terrestrial masses."

Considerable doubt was thrown on the accuracy of Young's formula for reduction to sea level by Wm. Sterneck's calculations, and the necessity for the term $\left(\frac{3h}{r}\cdot\frac{d}{D}\right)$ called in question. The formula is now used in the form

$$\frac{dg}{g}=\frac{2h}{r}\left(1-\frac{3}{4}\cdot\frac{d}{D}\right)$$

that is, the doubtful term has been decreased one-half.

In connection with mean density of the earth, the recent work of Prof. C. V. Boys, F.R.S., with the torsion balance, is of great interest and importance, as showing a method more likely to give accurate results.

The application of the pendulum which produced greatest excitement among physicists was perhaps Foucault's "Demonstration physique du mouvement de rotation de la Terre au moyen du Pendule," which appeared in 1851; no less than 78 memoirs were published that same year, and 31 the following year, as compared with 7 in 1849, and 3 in 1850. He showed the rotation of the earth by means of the rotation of the plane of oscillation of a pendulum, free to oscillate in any plane through its axis.

In *Nature*, XXII., 1880, Mr. C. R. Cross describes an interesting method of obtaining a permanent record of Foucault's pendulum experiment. A pendulum 16 feet long, consisting of a 5-pound cannon ball suspended by a wire, was made to oscillate; the ball carried a bristle, which served as a marker. At intervals of 15, 30, or 60 minutes, a smoked glass was raised to receive the markings of the bristle, care being taken to give the glass no rotation; the inclination of the tracings was clearly shown.

Without reference to other minor applications of the pendulum, and the anomalies which appear, "defying all attempts at explanation," this sketch will be concluded by the chief reasons now given for continuing to conduct experiments for the determination of gravity, absolute or differential. In a conference on gravity determinations held in Washington, in 1882, the following persons took part: J. E. Hilgard, Superintendent of the United States Coast and Geodetic Survey; Major Herschel, R.E.; Prof. C. S. Peirce, Prof. S. Newcomb (on the part of astronomy); and Messrs. George Davidson and C. A. Schott (on the part of geodesy); Major J. W. Powell, Director of the United States Geological Survey (on the part of geology), was unable to attend.

A number of reasons were given for the prosecution of pendulum experiments:

1°. The determination of the figure of the earth.

2°. The obtaining of a means to preserve and transmit to posterity an exact knowledge of the length of the yard and metre.

3°. The inferences which may be drawn in regard to the geological constitution of underlying strata.

4°. The use of gravity as the unit of force, and the consequent necessity for the accurate determination of its variations.

5°. The perfecting of our knowledge of the earth's crust, so that we may be able to infer from the vertical attractions of mountains what their horizontal attraction must be, and the deflection produced on a plumb line.

6°. The relation of the force of gravity to latitude and longitude. "The force of gravity is related in the same way to the latitude and longitude as the intensity of magnetic force is related to magnetical declination and inclination, and as a magnetical survey would be held to be imperfect in which measurements of intensity were omitted, to the same extent must a geodetical survey be held to be imperfect in which the determinations of gravity had been omitted."

The principal object among the foregoing is that of determining the actual figure of the earth, and its variations from the supposed mean figure. "Bearing in mind the large body of past work which has undoubtedly sufficed to indicate very closely what the mean figure is, it should now be recognized as more particularly the object of pendulum research to enlarge our knowledge of the *irregularities of figure*, rather than to aim at improving the *mean* figure."—Major Herschel.

For this purpose the invariable pendulum was most strongly recommended, as giving results in every way comparable.

The general opinion was that the probable accidental error in the results should not exceed $\frac{1}{200,000}$, and the total error to be feared $\frac{1}{100,000}$ of the value of the gravity. Four classes of errors must be taken into consideration :

1°. Those nearly constant throughout the work at one station, arising from flexure of support or other fixed conditions.

2°. Those constant for a time, but varying from day to day, as the temperature, pressure, etc.

3°. Those continually varying through the observation.

4°. Those arising from the comparison of the pendulum with the timepiece.

The reasons given by this conference for the prosecution of pendulum research, and the problems to be solved by its aid, tend to show more than ever the value of continued and accurate experiments. "L'Astronomie, la Géodesié et la Géologié sont toutes trois intéresseés à l'extension des mesures du pendule."

THE ACCOUNT OF AN EXPERIMENT TO DETERMINE THE ACCELERATION OF GRAVITY AT TORONTO BY MEANS OF A KATER'S PENDULUM.

This experiment, which has been extended over a period of three months or more, up to the present, has been conducted in a room known as the instrument room, on the ground floor of the School of Practical Science, situated at a distance of 500 feet from the public street. The room is about 30 ft. × 27 ft., with a ceiling 11 ft. high, is lighted by four large windows, all fitted closely with double sashes, and has only one doorway, which opens into the large entrance hall. To prevent currents of air, or sudden changes of temperature, this doorway is provided with two doors with about a foot of space between, each fitted with a sliding panel in the lower half; these leave two openings 18 in. × 6 in., not, however, opposite each other, and provide for the passage of air. It might be mentioned, also, that great care is exercised in the heating of the room to keep it at an even temperature. During the time of the experiment the thermometer varied from 61° to 67° F., with an average of 64°-5°, and no sudden changes.

The instruments used in the experiment were:

1. The Kater's pendulum.
2. An astronomical clock.
3. A chronograph.
4. A comparator with microscopes.
5. A standard bar.
6. A telescope mounted on a tripod.
7. A small lamp.
8. A barometer and several thermometers.

The Kater's pendulum, of which a drawing is shown (Fig. 1.), was manufactured by Nalder Bros. & Co., Clerkenwell, London, England. It was ordered for the School of Science in July, reached here in October, 1895, and its first use, involving the learning of all its peculiarities, has been by the writer for the determination of gravity. It consists of a cylindrical rod made of steel, 50¾ inches long, and a little less than ½ in. in diameter; in each end is screwed a small brass pointer to indicate the size of the arc of vibration. There are three weights, all movable, two of equal size, cylindrical in shape, and having an outer surface of lacquered brass; of these the heavier, weighing 1,107 grams, is near one end of the rod and outside the axis of suspension, the other, weighing 225 grams, is near the opposite end and between the axes of suspension. They are held in position by brass screws, which press against the rod. The third weight is about midway between the axes of suspension, and is a slider, the outside of which is covered with a thread bearing three nuts, one to bind the slider in position by means of a split at one end, the others movable, and serving to hold each other in place; the slider weighs 120 grams.

The axes of suspension are knife-edges, made of very fine steel, the two axes as nearly alike as possible; each consists of two triangular prisms, the faces terminating in the knife-edge having an inclination of 60°, and an ultimate angle of about 120°. The base of these prisms, that is, the face opposite the knife-edge, rests against a support consisting of a brass plate with rounded ends, about 2½ inches long, 1⅝ inches wide, and ¼ inch in thickness. This plate is joined to a collar of brass ⅝ inch long and an inch in diameter, which forms with the plate one solid piece. This support of the knife-edges is pierced by a cylindrical opening, into

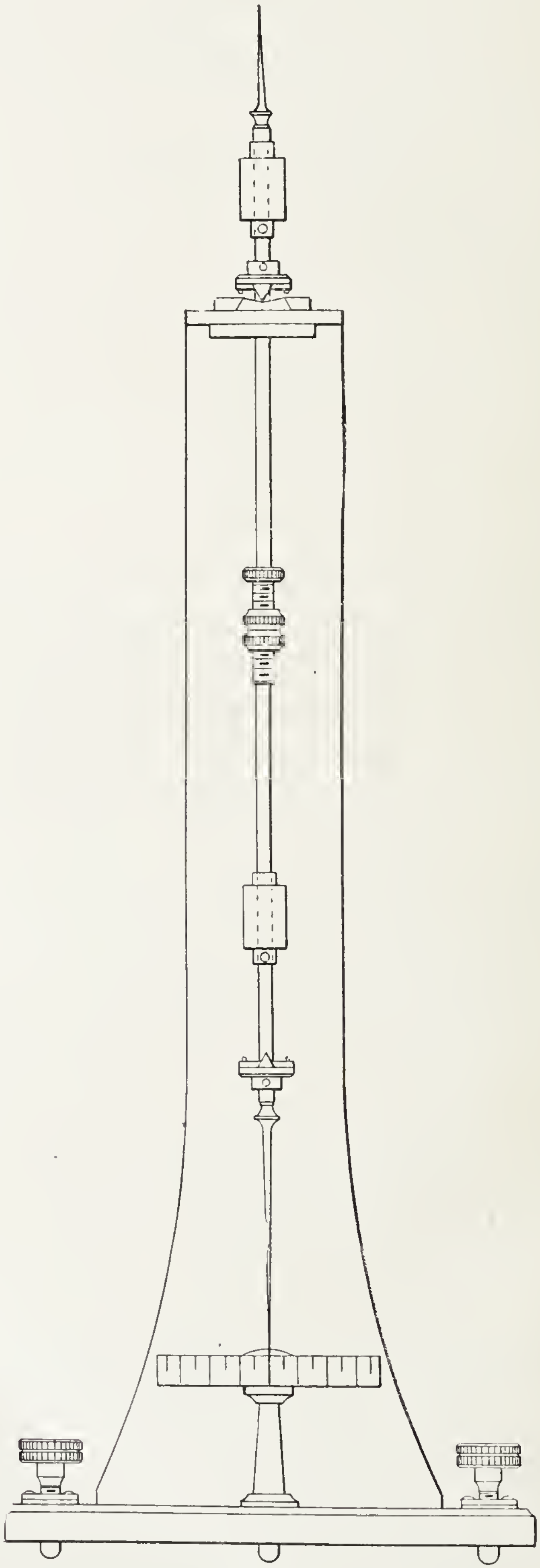


Fig. 1

which the rod of the pendulum fits closely; three steel screws pressing against the rod hold the support firmly in position. Each knife-edge is fastened to the brass plate by means of two smaller plates with bevelled edges, which press upon the sides of the knife-edge, and prevent it from moving in any direction; each of the smaller plates is held in place by two screws, which, like the former ones, may be tightened either by a screw-driver or an adjusting pin. The two knife edges, forming one axis of suspension, can be adjusted to have the same level, and be exactly in line before the block holding them is put on the rod.

The stand on which the pendulum swings consists of a column of cast steel, 4 feet high, 11 inches wide at its lowest part, 3½ inches wide at the top, ½ inch thick, strengthened by a buttress at the back reaching nearly to the top. The column rests on a rectangular metal base, 19 inches long, by 14 inches wide, and 1 inch thick, to which it is fastened by strong bolts. In the base are two levelling screws, as shown in the drawing, and a third point of support, consisting of a small leg or projection, at the side opposite the levelling screws. The top of the column is turned so that it ends in a horizontal plane 4½ inches by 3½ inches, nearly over the centre of the base, this small plane being steadied by a metal brace at one side, the whole column, buttress, horizontal plane, and brace, being cast in one piece. A rectangular opening is made at one side in this upper plane surface, into which the pendulum rod passes.

The plane of suspension consists of two pieces of agate, one for each knife-edge, forming an axis of suspension. Each is longer than the knife-edges, which are an inch long, and is wider at the base than at the top, being held in position by clamps made of brass plates, with bevelled edges; these are screwed firmly to the upper surface of the stand. The upper surface of the agate is **V** shaped, and the bottom of the **V** has been carefully prepared as a plane surface; this shape ensures the knife-edges resting on the same part of the plane at successive swings. The distance between the agates is slightly less than the distance between the knife-edges, so that the whole length of each knife-edge rests on the plane.

The stand of the pendulum rests on a stone cap 19 inches square by 6 inches thick, surmounting a brick pier, which is built on the solid ground beneath the floor, and extends to a depth of 2½ feet.

The astronomical clock used for observing the coincidences was manufactured by E. Howard & Son, Boston, Mass.; it is fastened to a heavy stone pillar, 10 ft. long, 2 ft. wide, and 1 ft thick, which is set in a solid brick pier 6 ft. square and 3 ft. deep, resting on a concrete foundation 6 in. thick. The pier is independent of the floor or walls of the building, and the clock is supposed not to be affected by the machinery in the School. To ensure greater accuracy in the time, the rate of the clock was compared each day during the time of the final observations with the Observatory clock, with which it has electrical connection; for this the writer is indebted to the kindness of Mr. Blake of the Observatory staff.

The chronograph used was in circuit with the clock, and registered automatically every two seconds, as measured by the clock; the circuit also included a break-circuit key, by which the observer could register the exact time of a coincidence without leaving his post at the telescope.

The comparator was used to measure the distance between the knife-edges on the pendulum; it was manufactured in Waterville, Maine, and put in position by Prof. Wm. Rogers. It consists of a heavy bed of iron about 10 ft. long, and supported on three piers; this bed has a way or track along which a carriage bearing a microscope can be moved on a horizontal plane in a straight line. Two methods of measuring may be adopted; in one the carriage is moved a certain fixed distance, determined by stops securely fastened in the track, the points of contact between the carriage and the stops being small projections of very hard steel. By means of a movable cross-thread a comparison is then made of this fixed distance first with the distance to be measured, and also with a length on the standard bar, by which the required distance is found in terms of some known length on the bar. In the other a second microscope is used, and the fixed distance is that between the cross-hairs of the microscopes. During the comparison of the required length with the standard bar, neither of the microscopes is moved, the comparison being made wholly by means of the micrometer screws and the movable cross-threads. The microscopes were manufactured by the Bausch & Lomb Optical Co., New York and Rochester.

The standard bar was made by Prof. Rogers in his laboratory at Waterville. It is a copy of a copy of the English standard yard kept at London, and the French standard metre, the first copies of which were made by Prof. Rogers at the request of the United States Government for comparison with the standards at Washington. This was bought for the School of Science, and was accompanied by a full description of the methods used and the care exercised in making it, as well as the first copies, also some comparisons with the originals which he has been able to make since that time. According to him, the metre (the one used in this experiment) is standard at a temperature of 14°.66 C., and expands 10.246 mikrons for 1°C. He also gives a table showing the correctness to the successive decimetre divisions.

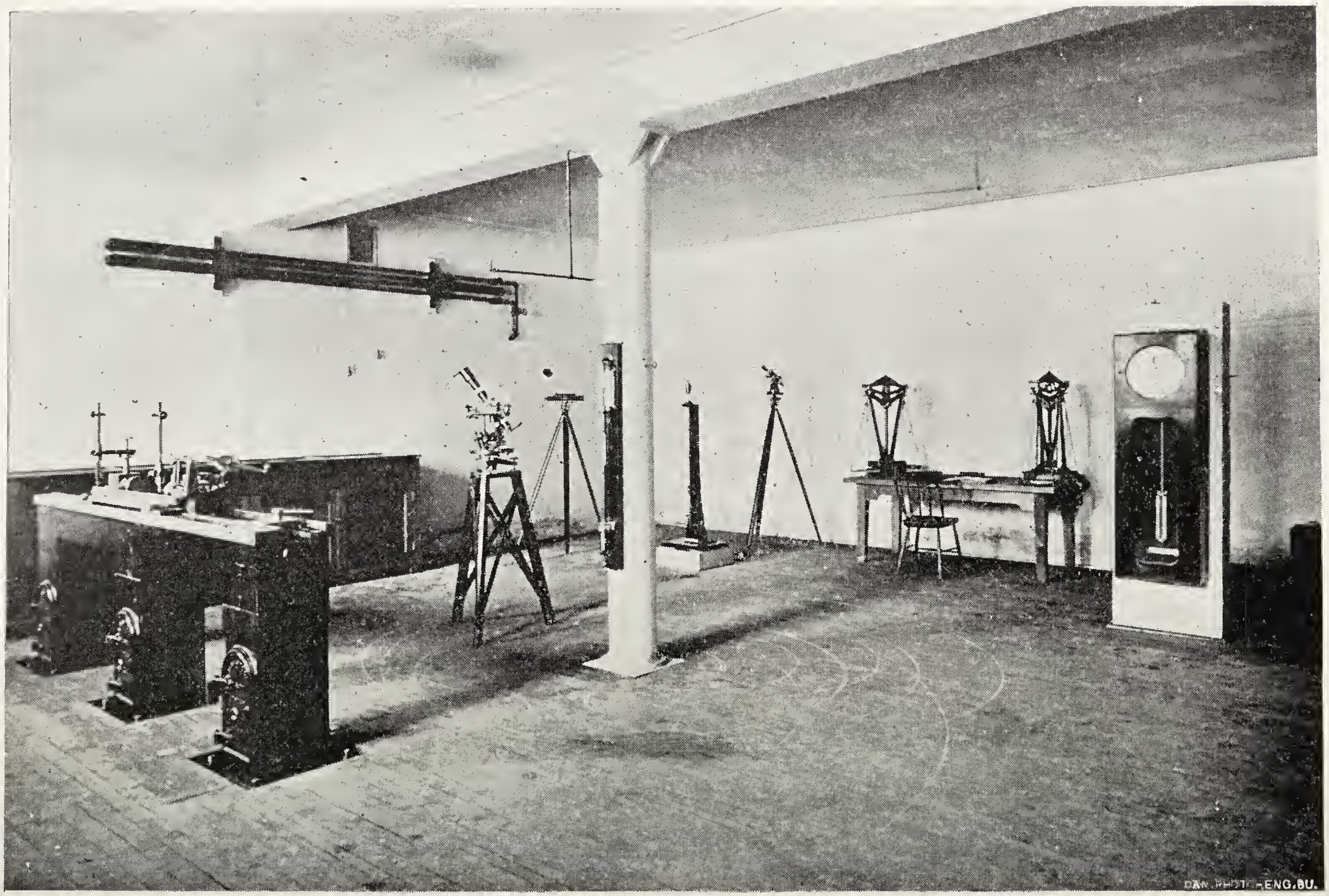


Fig. 2

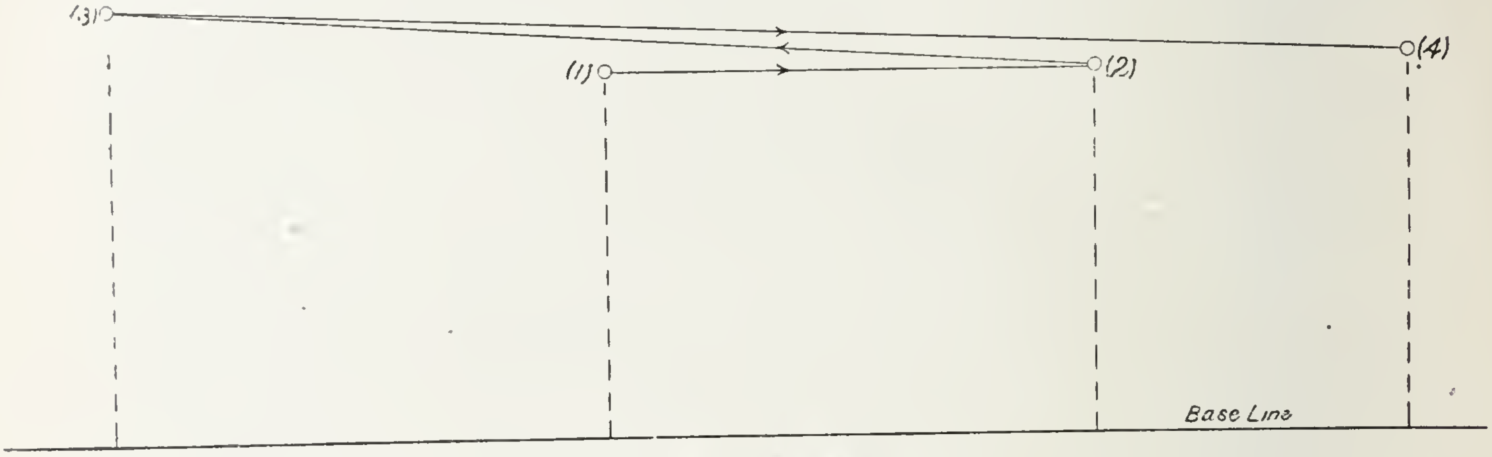
An ordinary surveyor's telescope mounted on a tripod was used for observing the flashes marking the coincidences. A small lamp belonging to a transit, with a lens sending out parallel rays, was set on another tripod on a small plane, whose height could be adjusted by a screw, to form the source of light.

The thermometers used were loaned by Mr. Rosebrugh, two Centigrade and one Fahrenheit. As these agreed with one another and with the one attached to the barometer, no test was made to determine any correction. The barometer is a fixture in the room, and was compared with the one in the Observatory when put in position.

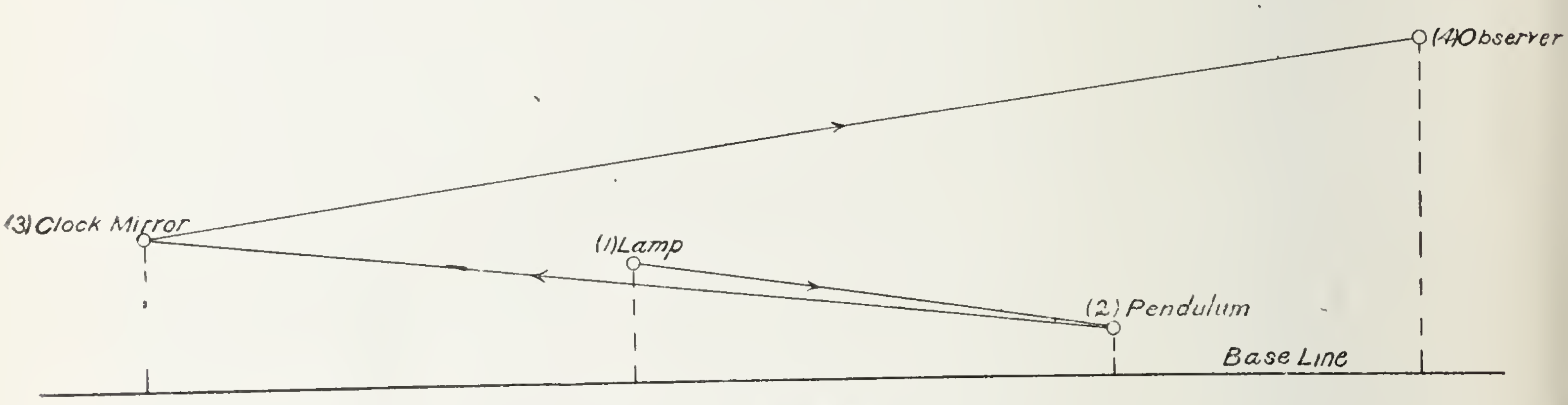
The accompanying cut (Fig. 2) shows the interior of the room and all the instruments except the lamp and the chronograph, as well as some other instruments kept in the room.

The first work in connection with the pendulum, after it had been set up, was to make the adjustment of the weights to bring the intervals between coincidences the same, or approximately so, for both positions. In order to avoid the error introduced by variation in the rate of the clock, an interval of about an hour was considered most suitable, and, assuming the length of the second's pendulum to be 39.11 inches for this latitude, the knife-edges were set a distance apart of 39.07 inches approximately. A great many observations were then made, first leaving the heavy weight fixed, and moving the lighter weight by short distances, over quite a length, to find the effect on the intervals, then moving the heavy weight slightly, and repeating the process. So far as the observations extended, any change in the position of the lighter weight produced the same effect on both intervals, that is, both were lengthened, or both shortened, the change when the heavy end of the pendulum was up being always greater than when it was down. The observations at this stage were made with the Kater's pendulum standing on the floor beside the clock, and the times of the coincidences of the two estimated as nearly as possible by the eye. Much time was spent at this work, as it took so long to make a single observation; at length the intervals were brought approximately together, and the next step was to get a more accurate method of observing the coincidences. The method then adopted, and adhered to throughout the experiment, was as follows:

The Kater's pendulum was set about 13 feet from the clock, almost in line with it at one side, and in such a position that the two pendulums oscillated in planes making a very small angle with each other. To each pendulum was attached a small mirror, as near the point of suspension as possible. About midway between the two the lamp was mounted on the tripod, so that the light from it fell on the mirror attached to the Kater's pendulum, was reflected to the one on the clock, and again reflected through the telescope to the eye of the observer, who stood about 17 feet from the clock. The plan and elevation showing the path of a ray of light from the lamp to the eye of the observer are given in the drawing (Fig. 3).



ELEVATION



PLAN

Fig. 3

The mirrors used were small, circular pieces of glass, about ⅝ inch in diameter, silvered on one side; the lens of the lamp was about the same size; but, though the source of light was only a small olive oil flame, it was found that too much light was being reflected to permit the accurate observation of a coincidence. To remedy this, a paper blackened with India ink was fastened over the lens of the lamp, leaving a horizontal opening ⅜ inch long and $\frac{1}{25}$ inch wide, in the centre of the paper, for the light to emerge. Similar papers with slits of the same size were put on both mirrors; later, another paper with a slit of not more than $\frac{1}{50}$ inch in width was put on the clock pendulum.

The adjustment of the apparatus was made when the Kater's pendulum was at rest; that is, at its lowest position for every swing, irrespective of amplitude. First, the light was moved to the right or left, till the reflection from the first mirror came in the vertical plane passing through the two mirrors; then its height was adjusted, till this reflection fell exactly on the slit in the second mirror, after which the telescope had to be adjusted to catch the second reflection. Some idea of the accuracy of adjustment required may be gathered from the small size of the pencil of light allowed to emerge from the lamp, and the still smaller size of the uncovered portions of the mirrors. It was found that a change of half a turn, or even less, of the screw which adjusted the plane holding the lamp produced a noticeable difference in the regularity of the coincidence intervals; that is, a change of $\frac{1}{100}$ of an inch in the height of the source of light could be detected in the course of an observation lasting forty minutes. Great care was necessary, also, that the wick should be the right height in the lamp, and the lamp itself placed in the proper position on its support. As it was necessary not to stop the clock, this adjustment was considered accurate when, with the Kater's pendulum absolutely at rest, a bright flash could be seen on the clock mirror at every swing of the pendulum. A still more delicate test of the accuracy of adjustment was found in the course of the experiment, which will be mentioned.

On account of the uniformity in the amplitude of the oscillations of the clock pendulum, it was not considered necessary to see the flash reflected from it at the instant it passed through its lowest position. The observations were taken when the clock pendulum was about one degree from the vertical; it was found that each time the two pendulums, while swinging, occupied these respective positions, that is, the Kater's, its lowest or the vertical position, and the clock pendulum the proper position to reflect into the telescope, the flash of light could be seen several times at intervals of two seconds; the time midway between the first and last flash was that taken for the coincidence.

Four coincidences occurred during a single interval:

1°. Both pendulums swinging to the right.
2°. Both pendulums swinging to the left.
3°. Kater's to the left and clock to the right.
4°. Clock to the right and Kater's to the left.

The interval or the time between corresponding coincidences was found by taking the difference between the times of the first and fifth, second and sixth, third and seventh, etc., as indicated on the chronograph. When the height of the lamp was just right, the time between the first and second coincidences was the same as that between the third and fourth, and that between the second and third the same as between the fourth and fifth. It was in this way that a change in the height of the lamp could be detected, or the delicate test before mentioned applied to adjust it to the proper height.

The foregoing method of observing coincidences recommends itself on the ground of being cheap, and, under the circumstances of the present experiment, easily prepared, though the extreme care necessary in making the adjustments, as well as keeping them, would show the necessity for more permanent fixtures in some respects. The method is believed to differ from any elsewhere described, and offers the advantage of helping to eliminate errors of observation by the number of coincidences occurring in each interval.

When the apparatus had been arranged, and observations were begun to determine the time of the coincidences accurately, it was found that the number of flashes which appeared at each coincidence was so great as to produce uncertainty concerning the time midway between the first and last flashes, for which reason it was decided to alter the distance between the knife-edges to make the interval about ten minutes instead of an hour. This was done with the assistance of Mr. Stewart, lecturer in the School of Science, the knife-edges being set at a distance apart of 38.85 in. approximately. This opportunity was taken to get the weight of the pendulum and each of its parts. A careful readjustment of the knife-edges was also made to get the two forming each axis of suspension exactly in line, also to get the two axes of suspension in the same plane; for these purposes the horizontal plane surface of the comparator was used as the testing surface. On setting the pendulum up again, its rate of oscillation was found to be so changed that only three flashes in general showed through the telescope at each coincidence; sometimes two, and sometimes four, were seen.

The work of adjusting the weights was then begun again to make the interval the same for both positions; this time the work proceeded more rapidly. To avoid correcting for amplitude at this stage, the pointer at the lower end of the pendulum was always pulled aside to the same mark on the scale when being started. The scale, which was not mentioned in the description of the pendulum, is graduated in degrees and tenths of a degree; it extends to three degrees on each side of the vertical, and is bolted to the base of the pendulum stand in such a position that the pointer hangs just before it.

In starting the pendulum, it was pulled aside to a certain mark, allowed to rest a moment, and then oscillated freely by its own weight; a lead pencil or small ruler was generally used to push it aside. Special care was taken not to touch the pendulum, or any part of it, with the bare hand; to lift it off in reversing a chamois was always used.

When the intervals had approached within about half a minute of each other, some disturbing influence was found to be at work, which so affected the pendulum in the position with the heavy end up that the interval showed a variation of more than a minute without any change in the weights. This was ascribed successively to various causes, the machinery in the building, the jarring due to the street cars, changes in temperature, and irregularities in the knife-edges; and a series of experiments, lasting more than a week, was conducted under all different conditions possible, to locate it definitely. No flaw could be detected in the knife-edges, and after experimenting on Sunday, when street cars and machinery were both stopped, and the temperature did not differ materially from the previous day, attention was turned to the agate planes, forming the plane of suspension, which, up to this time, had been assumed to form a perfectly level surface.

A careful examination of these showed that one agate was slightly too thin at one end, nearly $\frac{1}{100}$ of an inch, so that while one knife-edge rested through its whole length on the plane of suspension, the other rested only on a short distance at the higher end of the agate. To remedy this, it was assumed that the two knife-edges forming an axis of suspension were exactly in line, and perpendicular to the axis of the rod, as this adjustment had been very carefully made. The thin end of the agate was then raised slightly by thicknesses of paper, which was used as being a substance easily procured of uniform thickness. Two tests were applied to find when the knife-edges rested evenly on the agates: one by observing when the line of light, which showed where the two substances met, was uniform; the other by exerting pressure, to see if any motion of the end of the pendulum, perpendicular to its plane of oscillation, could be produced. When the proper number of thicknesses of paper had been inserted that both tests were satisfied, the agates were adjusted to bring the level surfaces at the bottom of the **V**'s exactly in line, and the adjustment of the weights was continued. Though the tests were not as rigid as might be desired, the absence of any appreciable irregularity in the time of the interval since this change was made in the agate tends to show that a high degree of accuracy was obtained.

When the intervals came within two or three seconds of each other, one being 10′ 8.″5, and the other about 10′ 10.″5, preparations were made for taking the final readings. Up to this time the only weight moved in the adjustment for this interval was the lighter of the two large weights, and it was supposed that the intervals could be brought together by moving the nuts of the screw of the slider. The following table shows the way in which the observations were recorded, and gives the results of the first swing intended to be used as a final observation :

SWING NO. I. A—HEAVY END DOWN.

Coincidences.	Semi-arc in Minutes.	Temperature.	Pressure in mm.	Interval.	Period in Seconds.	Correction for Amplitude	Period Corrected.
5h 58′ 23″ 59′ 26″	61	18.°C	745.25	....	....	....	....
6h 3′ 29″ 4′ 30″	58	......	....	....	....	....	....
8′ 32″ 9′ 34″	55	.....	....	10′ 8.5″	.9967240	−211	.9967029
13′ 39″ 14′ 38″	52	......	....	10′ 9″	268	−159	109
18′ 41″ 19′ 44″	49	......	....	10′ 9.″5	292	−142	150
23′ 47″ 24′ 48″	47	......	....	10′ 9″	268	−129	139
28′ 49″ 29′ 54″	45	......	....	10′,9″	268	−116	152
33′ 55″ 34′ 56″	43	17.°8	746	10′ 8″	215	−106	109

Mean period .9967115

I. B—HEAVY END UP.

Coincidences.	Semi-arc.	Temperature.	Pressure.	Interval.	Period Uncorrected.	Correction	Period Corrected.
5h 13′ 9″ 14′ 10″	52	18°	745	....	....	....	....
18′ 15″ 19′ 16″	47	......	....	....	....	....	....
23′ 21″ 24′ 22″	42	......	....	10′ 12″	.9967425	−116	.9967309
28′ 25″ 29′ 28″	38	......	....	10′ 11″	375	− 95	280
33′ 31″ 34′ 32″	35	....	....	10 ′10″	320	− 78	242
38′ 35″ 39′ 38″	32	......	....	10′ 10″	320	− 64	256
43′ 41″ 44′ 42″	29	.. ...	....	10′ 10″	320	− 54	266
48′ 45″ 49′ 48″	26	18°	745.25	10′ 10″	320	− 44	276

Mean period .9967271

The temperature was read at the beginning and end of the swing in each position from two thermometers attached to the pendulum stand, one at the top and one at the bottom; the one on the barometer was used as a check on the others; the pressure was read on the barometer at the same time. The reading for the amplitude of the semi-arc was taken by the eye always between the two coincidences, which came near together, as a result of the flash being seen when the clock pendulum was not at its vertical position.

The mean of the two intervals from the 1st to the 5th and 2nd to 6th coincidence was taken as the time of the interval, with initial and final amplitudes of the corresponding semi-arcs. The reduction to infinitely small arc was made on the period or time of a single oscillation by an adaptation of Borda's formula:

$$\nu = \frac{PM \sin \overline{\phi + \phi'} \sin \overline{\phi - \phi'}}{32 (\log \sin \phi - \log \sin \phi')}$$

where ν = correction to be subtracted from P,
P = period of a single oscillation,
M = modulus of common system of logarithms,
ϕ = initial semi-arc,
ϕ' = final semi-arc.

When five such swings had been made, it was discovered that one knife-edge was slightly loose; as it could not be ascertained when it had become so, it was decided not to use these results. After the screws had been tightened to hold this knife-edge firmly in place, the others were tested to see if they were solid. The lighter weight was then moved very slightly, to bring the intervals more nearly together, with the result as shown in the sixth and successive swings. It might be mentioned that every swing made from this time to the end of the experiment is recorded in the following table, p. 115. The attempt had been made throughout the work to determine the effect of the machinery, and of the jarring of the street cars, on the time of an oscillation; but though it is believed, and not without evidence, that these made the pendulum oscillate more slowly than it otherwise would, the variation in the time of the period due to the knife-edges resting in a slightly different way on the agates was sufficient to prevent the effect of the other disturbing causes from being measured accurately. To avoid, therefore, introducing an error which could not be corrected, all the swings, with the exception of one or two, were taken when the machinery in the building was not running, and four were taken on Sundays, that there might be the minimum amount of disturbing influence.

When the results of the first two swings had been calculated and found to agree more closely than had been considered probable, it was decided to use every means to prevent any personal judgment or prejudice from affecting the results.

Care was taken not to know the exact time of a coincidence or the length of an interval until the paper was taken off the chronograph, and the continued agreement of the results from day to day, for nearly two weeks, was accepted by the observer as evidence that his judgment was not materially affecting the results.

During the time of swings XVII. B and XVIII. B, the gas engine was running in the building; this rests on a foundation on the ground about 25 or 30 ft. from the pendulum, and was thought to be the cause of the period in B of both these swings being lengthened as compared with A. A good example of the effect of a disturbance caused by jarring is shown in the next table, showing the times of coincidences for the position B. Just after the eighth coincidence had been noted, the new stamp mill in the School of Science was started, and continued to run during the rest of the swing.

B.—FEB. 22ND.

Coincidences.	Intervals.
3 h. 9' 46"	
10' 46"	
14' 47"	
15' 47"	
19' 50"	10' 4"
20' 50"	
24' 51"	10' 4".5
25' 52"	
29' 54"	10' 4".5
30' 55"	
34' 57"	10' 5".5
35' 57"	
40' 1"	10' 6".5
41'	
45' 3"	10' 6".5
46' 4'	

The effect was seen at once in the lengthening of the interval, and what this jarring was found to do to a noticeable extent was ascribed in a lesser degree to the jarring produced by the gas engine and the dynamo. Unfortunately for the theory as applied to the gas engine, the same discrepancy occurred between the periods in one of the swings taken on Sunday (XX.) as in the two (XVII. and XVIII.) taken with the gas engine running, from which it was concluded that some other unknown influence was at work, probably some irregularity in the knife-edges.

After swing No. XI. the nuts on the slides were moved a half-turn towards the heavy weight to reduce the period in B, which up to this time was slightly longer than the period in A. After XIV. they were given a quarter turn from the heavy weight, and were not again moved during the experiment.

In order to estimate the probable accuracy of the value of the acceleration of gravity, commonly called g, as calculated from the foregoing results, the effect of an error of one second in the length of an interval of ten minutes was calculated from the formula

$$t = \pi \sqrt{\frac{l}{g}}$$

whence by differentiating and dividing is got the relation

$$\frac{dt}{t} = -\frac{1}{2}\frac{dg}{g}.$$

Substituting the values of dt, t, and g

$$\frac{.0000055}{.9966780} = -\frac{1}{2}\frac{dg}{980.\mathrm{xxx}}$$

$$dg = .001$$

that is, an error of one second in the interval produces a corresponding error of .001 cm. in the value of g. As the error in the mean of the seventeen swings is believed to be less than one second in the interval, the value of t is thought to be accurate enough to give g correct to the third decimal place in centimetres.

Two corrections besides that for the amplitude of oscillation were applied to the period as given by each swing :

1°. For the rate of the clock.

2°. For the temperature.

The rate of the clock was found each day except Sunday during the time of the experiment by a comparison with the Observatory clock generally twice a day, about 3 or 4 p.m., and about 8 p.m.

The error in the rate was calculated from these comparisons, in seconds lost per hour, usually about .03 per hour. A noticeable variation in the rate will be seen in that given for February 18th. It was found afterwards that the stamp mill was running in the School of Science when one of the comparisons was made, and to this is ascribed the change.

In the correction for temperature the coefficient of expansion for the steel rod of the pendulum was assumed to be that given by M. J. René Benoît in the "Travaux et memoirs de bureau international des poids et mesures," Vol. VI., 1888. The value of the coefficient of expansion was determined by a method devised in 1864 by M. Fizeau, of which Benoît says, "Le principe de la méthod de mesure imaginée, en 1864, par M. Fizeau, consiste, comme on le sait, à faire servir à la détermination exacte de trés petites variations de longeur les modifications qu'elles impriment à des franges d'interference produites entre deux surfaces planes et parallébes."

For "acier, recuit," he gives the value 10^{-9} ($10353 + 5.80\ t$) as the "moyenne de deux déterminations très concordantes, faites sur deux échantillons d 'acier, l' un francais, l' autre anglais, dans un intervalle de température plus considérable" (from 0° to 80°-85°). For the pendulum rod it was assumed $10^{-9}(10451.6)$ for the temperature 17°C., which was a mean for the experiment. The correction used was a purely theoretic one, deduced from the formula giving the time of an oscillation; but by using 17° as the standard temperature any error for the higher temperatures would be counterbalanced by a corresponding one for the lower ones. The length of the pendulum at the time of each swing was found in terms of its length at 17°, and the correction calculated

$$D = \frac{\sqrt{l_{17}} - \sqrt{l}}{\sqrt{l}}\ t$$

where D = correction to be added or subtracted,
l_{17} = length of pendulum at 17°,
l = length of pendulum during swing,
t = period of oscillation during swing.

The corrections and corrected values of the periods are given in the following table:

Date	No. of Swing.	Period Corrected for Arc.	Mean of the Period in Each Swing.	Mean Temperature.	Loss of Clock in Seconds per Hour.	Correction for Temperature.	Correction for Rate.	Mean Period Corrected.	Period for Position A Corrected.
Feb.	A	.9967054							
13	VI. B	7065	.9967060	17°.8	.03438	-42	-95	.9966923	.9966917
	A	.9967009							
"	VII. B	7019	.9967014	17°.9	"	-47	-95	872	867
	A	.9966929							
14	VIII. B	969	.9966949	18°.6	.03454	-84	-96	769	749
	A	.9966876							
15	IX. B	922	.9966899	18°.7	.03475	-90	-96	713	690
	A	.9966813							
16	X. B	841	.9966827	15°.4	"	+83	-96	814	801
	A	.9966823							
17	XI. B	892	.9966858	16°.2	.03705	+41	-103	796	761
	A	.9966849							
18	XII. B	836	9966843	16°.4	.09298	+31	-257	617	623
	A	.9966792							
19	XIII. B	758	.9966775	16°.8	.01602	+10	-44	758	775
	A	.9966844							
"	XIV. B	834	.9966839	16°.5	"	+26	-44	821	826
	A	.9966835							
20	XV. B	849	.9966842	17°.3	.02785	-16	-77	749	742
	A	.9966838							
21	XVI. B	871	.9966855	17°.5	.02870	-28	-79	748	731
	A	.9966787							
22	XVII. B	853	.9966820	16°.7	.02415	+16	-67	769	736
	A	.9966776							
"	XVIII. B	878	.9966827	16°.9	"	+4	-67	764	713
	A	.9966827							
23	XIX. B	834	.9966831	15°.6	.04006	+73	-111	793	789
	A	.9966774							
"	XX. B	882	.9966828	15°.5	"	+78	-111	795	741
	A	.9966748							
"	XXI. B	759	.9966754	15°.4	"	+83	-111	726	720
	A	.9966810							
24	XXII. B	865	.9966838	16°.8	.03494	+10	-97	751	723

Corrected value of the period :

1°. Mean of two positions, .9966775 sec.

2°. Heavy and down, A, .9966759 sec.

The latter of these is used as being less liable to error from disturbing causes.

The unknown quantity, which had yet to be determined, was the length of the pendulum or the distance between the knife-edges, in the determination of which even greater accuracy, if possible, is desirable than in the measurement of the period of oscillation.

The first step in the work was the finding of the value of a division on the micrometer head of the microscopes belonging to the comparator. This was done by measuring the successive millimetres of one centimetre on the standard bar, and reducing the lengths to the temperature 14°.66 ;

the centimetre used for this purpose was the one in which the measurement for the length of the pendulum would be made, from the 98th to the 99th division. As the field of view included more than a millimetre in length, each measurement was made by means of the movable cross-threads only. The average of ten different measurements of the ten millimetres was taken as the number of micrometer divisions in one millimetre.

The results were as follows for the average of each measurement :

1°. For the microscope on the carriage—

1	2205.13
2	2204.87
3	2205.02
4	2204.87
5	2205.45
6	2204.84
7	2204.99
8	2205.10
9	2204.90
10	2205.10
Mean	2205.02 divisions to 1 mm.

2°. For the fixed miscroscope—

1	2260.58
2	2260.71
3	2260.45
4	2260.55
5	2259.61
6	2260.56
7	2261.36
8	2259.90
9	2260.90
10	2261.10
Mean	2260.57 divisions to 1 mm.

From these results the value of a division was taken as

$$\frac{1}{2205.02} \text{ mm. for the former,}$$

$$\frac{1}{2260.57} \text{ mm. for the latter.}$$

When these observations were completed, a comparison was made with a set of measurements taken in the same way some months previously, on the 51st centimetre of the bar ; that calculation gave 2205.12 divisions to 1 millimetre for the first microscope, a result which agrees closely with the one used.

It was intended at first to use only one microscope, and measure the distance between the knife-edges by means of the stops, after having made careful tests for the corrections to the decimetre divisions on the standard bar to compare with those given by Professor Rogers.

But from some cause not quite determined, the use of the stops was not found satisfactory. When the carriage bearing the microscope was brought against the stop, and its position determined by finding the distance in micrometer divisions between the fixed cross-thread of the microscope and a graduation mark on the bar, successive readings for the same positions of the carriage, which was brought up to the stop afresh for each reading, were found to vary by quantities too large to be eliminated by taking even a very great number of readings. Whether this was due to lack of skill in manipulating the apparatus, to slipping of the carriage, to the elasticity of the points of contact of carriage and stop, to some slight disarrangement of the mechanism of the carriage, or to some other unknown cause, was not fully ascertained, but after a lengthened series of experiments it was attributed to a defect in the design of the comparator. The carriage is a heavy mass of iron weighing 60 or 75 lbs., and this can hardly be brought against a small stop with just the same force every time in succession; and, as the force varies, even though slightly, the compression of the steel projections is different, or their elasticity causes the carriage to slip back to a different position. The other method of measuring, by means of the second microscope held by a fixed stand, had to be adopted; the tests for the corrections to the decimeter divisions could not be made, as so short a distance as one decimetre could not be measured with the two microscopes.

The focal length of the microscopes was found to be too short to permit observations being made directly on the knife-edge, the sloping side of which prevented the microscope from coming near enough to the edge. Observations on the ends of the knife-edges were not satisfactory, as the position of the edge was not clearly defined, and a slight rounding off was also noticeable, which was thought sufficient to prevent even a fair degree of accuracy in taking the distance between the ends of the knife-edges as the distance between the axes of the pendulum. Use was therefore made of two subsidiary blocks in the manner described by Captain Kater; these were prepared by Mr. Plaskett, electrical machinist of the University. He first procured two pieces of hardened steel, 4½ in. long by 3 in. wide, and 1¼ in. thick. One of the largest faces of each was then planed off, scraped and ground to as near a perfect plane as possible; when rubbed together, they were found to adhere with sufficient force to lift their own weight. With these two faces placed together, the pieces were then firmly fastened in the lathe; for about half its length this block, for the two now appeared as one piece 4½ in. long by 3 in. square, was turned to form a cylinder about 3 in. in diameter and 2 in. long, and a ¾ in. hole bored in the centre.

The round surface of this cylinder was then smoothed and polished with fine emery powder and rouge, and the exposed end planed, scraped, and polished to a plane surface; a surface plate belonging to the comparator, and prepared by Professor Rogers, was used as the testing surface for this purpose; from it another was prepared which was ground against the end of the cylinder. When the smoothing and polishing were completed, this cylinder was cut off from the rest of the block. It separated into two pieces, each being a part of one of the original blocks; when the finished ends were rubbed together slightly, they adhered quite firmly to each other, showing that a close approximation to a plane surface had been secured.

On placing the polished round surface under the microscope, a number of marks made by the emery powder were distinctly visible. A definite spot was chosen on each where two marks crossed, their position being defined by a fine line drawn with a razor edge parallel to the axis of the blocks; the line was drawn when the two blocks were placed with their finished ends together, and showed under the microscope with about the same distinctness as the graduation marks on the standard bar. Nine rubber bands, each exerting a pressure of 2 lbs. approximately, as tested by a spring balance, were put around the two blocks to hold them firmly together, the ends having been carefully cleaned before. They were then put on the bed of the comparator under the microscope, and a number of measurements taken of the distance between the chosen marks already mentioned, with the following results:

FIRST MICROSCOPE

		Blocks Reversed.	
1542	divisions	1540.5	divisions.
1542	"	1541	"
1542.5	"	1542	"
1541.5	"	1543	"
1541	"	1543	"
1543.5	"	1541	"

Mean distance .69927 mm.

SECOND MICROSCOPE.

		Blocks Reversed.	
1584	divisions	1582	divisions
1585	"	1583	"
1585	"	1582	"
1584.5	"	1582	"
1584.5	"	1581	"
1583	"	1582.5	"

Mean distance .70036 mm.

Mean value of the distance as determined by the two microscopes,

.6998 mm.

It is worthy of mention that these blocks were so nearly the same thickness that, when placed end to end on the bed of the comparator, both could be distinctly seen under the microscope where a change of $\frac{1}{200}$ in. in the distance from the object-glass throws the object to be observed entirely out of focus.

The pendulum was next removed from the stand and laid on the bed of the comparator; it was supported by five blocks of uniform thickness to prevent flexure. The knife-edges were placed in a horizontal position, and the pendulum rod secured from slipping or rolling by a small wedge in a groove in one of the blocks; the groove was made by nailing two small pieces of wood on the block, half an inch apart. The blocks themselves were made of a piece of very dry walnut which has been lying in the basement of the University for many years; they were 3 inches long by 1½ inches wide and ¾ inch thick, and were prepared by Mr. Plaskett; when in use, they were placed on edge. The steel blocks already described were then placed on the pendulum, with the groove on their under side fitting over the rod; each had its plane surface against a knife-edge, and was held firmly in position by two rubber bands.

Afterwards the microscopes were set so that the marks on the blocks, between which the distance had been measured, came in the centre of the field of vision; while no difficulty was found in identifying the marks, some time was necessary to adjust the microscopes properly without disturbing the arrangement of the pendulum.

The two thermometers were placed on smaller wooden blocks, so that their whole length was against the pendulum rod, and the whole was left until the next day to allow the change in the temperature due to handling the rod to pass away. The position of the marks on the blocks with reference to the fixed cross-threads was observed at intervals of a couple of hours for the next two days, during which, fortunately, there was no machinery running, and no jarring to shift the position of the apparatus in even the slightest appreciable degree. The movable cross-thread of each microscope was adjusted exactly over the chosen mark on one of the blocks, and its distance from the fixed cross-thread read in micrometer divisions. These distances, one for each microscope, had then to be added to or subtracted from the distance between the fixed cross-threads, called *d*, in order to determine the distance between the marks on the blocks.

The following table shows the readings taken, the temperature of the rod, and the distance calculated in terms of *d*. Each reading is the mean of a number taken at the same time, and among these the greatest variation seldom exceeded one micrometer division.

Temperature.	Microscope 1°.		Microscope 2°.		Distance between the Marks on the Blocks.
	No. of Micrometer Divisions.	Length in mm.	No. of Micrometer Divisions.	Length in mm.	
18°.2	– 343	.1556 mm.	– 576	.2548 mm.	*d* – .4104 mm.
18°.9	– 334	.1515 "	– 572	.2530 "	*d* – .4045 "
18°.7	– 339	.1537 "	– 574	.2539 "	*d* – .4076 "
18°.9	– 338	.1533 "	– 572	.2530 "	*d* – .4063 "
18°.9	– 341	.1547 "	– 572	.2530 "	*d* – .4077 "
19°.	– 334	.1515 "	– 578	.2557 "	*d* – .4072 "
19°.3	– 333	.1510 "	– 575	.2544 "	*d* – .4054 "
19°.2	– 332	.1506 "	– 573	.2535 "	*d* – .4041 "
19°.	– 338	.1533 "	– 575	.2544 "	*d* – .4077 "
18°.6	– 344	.1560 "	– 578	.2557 "	*d* – .4117 "
18°.5	– 346	.1569 "	– 577	.2552 "	*d* – .4121 "
18°.3	– 349	.1583 "	– 578	.2557 "	*d* – .4140 "

To find *d*, the distance between the fixed cross-threads of the microscopes, the pendulum was removed from the comparator, and the standard bar placed under the microscopes so that the zero graduation mark came in the field of view of one; the 986th millimetre division was then found to come in the field of view of the other. After adjusting it as carefully as possible, and without touching the microscopes, readings were taken to find the distance of the graduation mark in each field of view from the fixed cross-threads, whence in the same manner as in the former comparison *d* was found in terms of a known length on the standard bar. In making the calculations, this length was assumed to be 986 mm at 14°.66 C., and the coefficient of expansion to be 10^{-9}(10246), the values given by Professor Rogers. The following table shows the results.

Temperature.	Microscope 1°.		Microscope 2°.		*d* Distance between Fixed Cross-threads.
	No. of Micrometer Divisions.	Length in mm.	No. of Micrometer Divisions.	Length in mm.	
18°.7	– 95	.0431 mm.	+ 115	.0509 mm.	986 0414 – .0078
	– 96	.0435 "	+ 114	.0504 "	– .0069
	– 95	.0431 "	+ 117	.0518 "	– .0087
	– 96	.0435 "	+ 116	.0513 "	– .0078
18°.1	– 100	.0454 "	+ 108	.0478 "	986.0352 – .0024
	– 100	.0454 "	+ 107	.0473 "	– .0019
	– 99	.0449 "	+ 104	0460 "	– .0011
	– 99	.0449 "	+ 105	.0465 "	– .0016
18°.2	– 98	.0444 "	+ 106	.0469 "	986 0363 – .0025
	– 98	.0444 "	+ 105	.0465 "	– .0021

Mean value of *d* from above—986.0336 mm.

It was assumed that the expansion of the heavy bed of the comparator to which the microscopes were attached would be negligible for the small changes in temperature from the time when the pendulum was being measured to the time when the standard bar was being observed, that is, d was assumed constant. As the change in temperature of the pendulum rod and the standard bar during the three days of the observation was only 1° C. that of the bed of the comparator would be less on account of its mass; hence the error introduced would be very small.

To find the distance in millimetres between the marks on the blocks, when in position on the pendulum rod, the value of d was substituted n the first table (p. 120), after which this distance was found for a temperature of 17°, assuming $10^{-9}(10452)$ as the coefficient of expansion of the rod.

The next table shows the results of these calculations.

Temperature.	Distance in mm. at Observed Temperature.		Correction for Temperature.	Distance at 17°C.
18°.2	986.0336 − .4104	985.6232	− .0125 mm.	985.6107 mm.
18°.9	− .4045	.6291	− .0198 "	.6093 "
18°.7	− .4076	.6260	− .0178 "	.6082 "
18°.9	− .4063	.6273	− .0198 "	.6075 "
18°.9	− .4077	.6259	− .0198 "	.6061 "
19°.	− .4072	.6264	− .0209 "	.6055 "
19°.3	− .4054	.6282	− .0240 "	.6042 "
19°.3	− .4041	.6295	− .0240 "	.6055 "
19°.	− .4077	.6259	− .0209 "	.6050 "
18°.6	− .4117	.6219	− .0167 "	.6052 "
18°.5	− .4121	.6215	− .0157 "	.6058 "
18°.3	− .4140	.6196	− .0134 "	.6062 "

Mean value for distance between the marks on the blocks—985.6066 mm.

Distance between knife-edges, that is, length of the simple equivalent pendulum,

$$l = 985.6066 + .6998 \text{ mm.}$$
$$= 986.306 \text{ mm.}$$
$$\text{and } t = .9966759 \text{ sec.}$$

whence by calculation

$$g = 979.949.$$

CORRECTION FOR BUOYANCY.

The weight of the pendulum is 3160.2 grams. The volume of air it displaces is 492 c.c. approximately, as determined by a careful measurement of all its parts.

The weight of this volume of air is

$$\frac{28.86}{22327} \times \frac{492}{1} \times \frac{273}{273+t} \times \frac{p}{760}$$

where t is the temperature
and p is the pressure.

The mean value of the weight of air displaced calculated from the above formula for the 17 swings of the pendulum, at mean temperature and pressure during the time of swing=.5892 grams.

Using Kater's correction for buoyancy, g must be increased in the ratio

$$.5892 : 3160.2 ; \text{ i.e., } 1 : 5363.54,$$

whence $g=979.949 + .1827$
$=980.132$.

Using Baily's correction for reduction to vacuum as more exact, this correction should be multiplied by 1.945, the experimental value of the multiplier found for a Kater's reversible pendulum with a half-inch rod, and swinging heavy end down. The correction then becomes

$.1827 \times 1.945 = .3554$,
and $g=980.304$,
also $l_\phi=99.3256$ cm.

Apply the formula $$\frac{dg}{g} = \frac{2h}{r}\left(1 - \frac{3}{4}\frac{d}{D}\right)$$ for reduction to sea level.

$h=350$ feet
$g=980.304$
$\frac{d}{D}=\frac{1}{2}$
$\log \frac{r}{r_0} = \bar{1}.9993101$ (Chauvenet's Astronomical Tables).
$r_0=20923600$ feet, equatorial radius.

whence $dg=.021$.
$g=980\ 325$.
$l_\phi=99\ 3276$ cm., at sea level.

When the measurement had been completed, another observation was made on the length of the period of oscillation to see if the knife-edges had undergone any perceptible alteration. The values of the period given by this swing, without corrections for temperature and clock-rate, were

A. .9966841 sec.
B. .9966870 "

which agree almost exactly with the former results.

Another set of measurements was then undertaken by the same method as the first, and under conditions slightly more favorable, as the mean temperature of the rod while being measured was almost exactly 17°, with slight variations above and below; distance between the knife-edges from second measurement,

986.304 mm.

That this came so near to the former result tends to show that the probable error in the length due to errors of observation is very small. There are two indeterminate sources of error: the unknown expansion of the bed of the comparator during the time of measurement, and irregularities or defects in the subsidiary blocks. The error due to the former could hardly be greater than .011 mm, which would be the expansion due to a change of 1° in the temperature of the cast-iron bed, while it would probably be much less as the temperature of the room only changed about 1° during the measurement, and the change in so great a mass of iron would be much slower. There is no means of estimating the error due to the latter cause, but assuming it as .01 mm, the greatest error in the length of the pendulum, supposing the errors from all sources to be in the same sense, would be about .022 mm. The corresponding greatest error in the value of g would be .022, while the probable error in this value is estimated by the writer at .01.

Helmert's formula, $g = 980.5934 - 2.5967 \cos 2\phi$, for finding the value of gravity at any latitude, gives 980.472 for the latitude of Toronto. The observed value given above agrees as closely with this as many of the observed values on this continent do with the values computed by the formula, and more closely than some given in recent years by the most eminent observers. This seeming discrepancy between the computed and observed values may be understood when it is remembered that the constants in Helmert's formula are calculated upon an hypothesis concerning the figure of the earth, based on a limited number of observations of the acceleration of gravity, while no allowance is made for variations due to local causes.

In the present instance, the proximity of the large body of water, Lake Ontario, and the absence of known rocky or other formation of high specific gravity in the vicinity, would indicate that the acceleration of gravity here should be smaller than would otherwise be expected.

CONCLUSION.

In collecting material for the foregoing historical sketch of the pendulum and its applications, the writer has not had time nor opportunity to consult all or nearly all the original memoirs on the subject. Such a task would be impossible in so limited a time with a bibliography comprising over 750 authors and more than 1,300 different published articles, many of which are to be found only in the libraries of Europe. This important work was done recently at the instance of "la Société Francaise de Physique," by M. C. Wolf, the eminent astronomer of Paris. Under his direction, this society published in 1889, in Tome IV. of their "Collection de Memoires relatifs à la Physique," the complete bibliography of the pendulum from the standpoint of Physics, accompanied by an historical sketch, and a number of the most important original memoirs, including those of La Condamine, Borda, and Cassini, Capt. Kater, M. de Prony, and F. W. Bessel. To the memoirs and extracts this work contains, and especially to the bibliography, this writer is much indebted. A list (not complete) of works consulted is given below.

"An account of experiments for determining the length of the pendulum vibrating seconds in the latitude of London": H. Kater, *Phil. Trans.*,* 1818.

"An account of experiments for determining the variation in the length of the second's pendulum at the principal stations in the trigonometrical survey of Great Britain": H. Kater, *Phil. Trans.*,* 1819.

"Remarks on the probabilities of error in physical observations, and on the density of the earth, considered especially with regard to the reduction of experiments on the pendulum": Dr. Young, *Phil. Trans.*,* 1819.

"Philosophise naturalis Principia Mathematica": Newton, 1686.

"On the discordancies in the results of the method for determining the length of the simple pendulum": Baily, *Phil. Magaz.*, 5, 1829.

"Experiments to determine the difference in the number of vibrations made by an invariable pendulum in the Royal Observatory at Greenwich, and in the house in London in which Capt. Kater's experiments were made": Sir Edward Sabine, *Phil. Trans.*, 1829.

"Notice on the reduction to a vacuum of Capt. Kater's convertible pendulum": *Ibid.*

"On the reduction to a vacuum of an invariable pendulum": *Ibid.*

"Account of experiments undertaken in the Harton colliery for the purpose of discovering the mean density of the earth": Sir G B. Airy, *Phil. Trans.*, 1856.

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*These three volumes of the Philosophical Transactions were kindly loaned by the Parliamentary librarian at Ottawa.

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"Journal de Physique": VIII., 1889.

" De la mesure du pendule à St. Domingue": M. de la Condamine, 1735.

" Expériences pour connaitre la longuer du pendule qui bat les secondes à Paris": Mm. Borda et Cassini, 1810.

" Méthode pour déterminer la longuer du Pendule simple qui bat les secondes, et pour trouver, en général, les positions des centres de gravité et d'oscillation, et le moment d'inertie d'un corps de forme quel conque": M. de Prony, 1800.

" Recherches sur la longuer du Pendule simple qui bat la seconde": F. W. Bessel, 1826.

THE ACTION OF HEAT ON CEMENT

By J. S. Dobie, Grad. S.P.S.

The modern tendency towards large and high buildings, with a skeleton structure of steel, has made the question of fire prevention and protection one of the most vital importance to architects, manufacturers, engineers, and builders in general. Countless experiments have been made to devise some means of preventing iron and steel columns and girders from buckling under great heat. Plainly, the only way this can be done is by so protecting the metal that heat cannot come into contact with the metal surface.

Experiments have also been made, and numerous schemes introduced, to devise some means of making a floor between the girders that will withstand the action of fire, and so prevent a fire, even if started, from spreading from one flat to another. Hollow tile, brick, and terra cotta have been tried with indifferent success; and at present the tendency is towards using Portland cement or concrete as a protection for ironwork.

It is not the purpose of this paper to propose or condemn any scheme, or to introduce any new one; but rather to show what really may be expected from a mass of concrete or cement when subjected to great heat. The writer has carefully examined all available literature upon the subject, including books and trade catalogues; and, while many give tests which are claimed to be eminently satisfactory, still, in almost every case, the accounts give such meagre information about the tests themselves as to be almost useless, as far as information is concerned, and certainly so as far as comparisons with each other are concerned. The information as to the action of the cement itself is, in every case, very meagre; and all the information given refers only to the conduct of the system tested, and no information whatever is given as to its condition afterwards.

In making these tests three brands of cement were used—two Canadian brands: "Star," manufactured at Deseronto, and "Samson," from Owen Sound; one foreign brand, "Jossen," of Belgium manufacture. These cements were thoroughly tested for fineness, strength, and "blowing" before using, and were found to be first-class. The "Star" and "Jossen" were comparatively slow-setting, and the "Samson" set very rapidly.

Tests were made upon neat briquettes and sand briquettes, mixed in proportions of one sand to one cement, two sand to one cement, and three sand to one cement. The age of the briquettes varied from two months to about four years. Over two hundred briquettes were used in making the tests.

The briquettes were heated in a small assay furnace, heated by a large gas burner, and which gave a range of temperatures of from about 650° Fahrenheit to about 1775° Fahrenheit.

The temperatures were determined by means of a water calorimeter; the temperature of the furnace being obtained from the rise in temperature of a pint of water, in which had been immersed an iron ball of known weight, and which was heated to the temperature of the furnace. The temperatures given are approximately correct. The calorimeter gave good results—different readings, under the same conditions, rarely differing by more than 10° or 15°, which is very close for such high temperatures.

On heating the briquette and removing from the furnace, the first thing noticed was a loss in weight in the briquette; and almost all neat briquettes showed cracks, some large and some small. Some sand briquettes also showed cracks, but not to the same extent as in the neat briquettes; but there was no exception to the change in weight. This loss in weight is due to the fact that the hardened cement is a compound of hydrated crystals of aluminium silicate and calcium silicate, and the heat drives off the water of crystallization, and the loss in weight corresponds to the amount of water of crystallization driven off by the heat. Now, since the crystals depend upon the water for their formation, it is evident that when the water is removed the crystals are destroyed, and the cement ruined. Such was found to be the case in every instance.

The briquettes, after cooling sufficiently to allow handling, were broken in the testing machine, the load being applied at the rate of about 400 pounds per minute. The result showed a marked decrease in the tensile strength, as reference to Tables I. and II. will show; and, under the best conditions, this loss in tensile strength showed an approximate proportion to the loss in weight. Briquettes which lost 19 or 20 per cent. of weight, which is practically the amount of water required for proper crystallization, were practically unable to resist any load whatever, and in very few cases possessed 10 per cent. of their original strength.

The effect of different temperatures was rather peculiar. Briquettes placed immediately into a temperature of about 1775° Fahrenheit showed a very great loss in strength for a very small loss in weight, and did not appear to follow this law of proportion between losses of weight and strength, at least not nearly so well as briquettes treated differently. When the briquettes were gradually heated, however, and allowed to slowly rise to the temperature of the furnace, this law was followed quite closely, as reference to tables will show. The plotted curves give a good idea of the effect of slow and rapid heating on the relation of the cement to this law. This is accounted for by the fact that the cold briquette, on being placed in the furnace at such a great heat, is immediately subjected to very considerable internal stresses, due to the expansion of the outside of the briquette before any water of crystallization at all is driven off. Briquettes, heated gradually, were not subjected to these internal stresses to nearly the same extent as those which were heated very suddenly.

An attempt was made to discover, if possible, a critical temperature to which it would be possible to subject the cement without danger of injury to the crystals, and where the cement would retain its cohesive powers. It was found that, if such a temperature existed, it was below the lowest temperature generated by the furnace, which was considerably below red heat. The lowest temperature had the same effect as the highest, excepting, of course, that with the lower temperature a longer time was required to effect the same reduction of weight than with a higher one. The lowest temperature necessary to destroy the cement was not determined, but is probably quite low. The following quotation from Heath's "Manual of Lime and Cement" is interesting regarding this. "Even good Portland cement concrete, if exposed to the weather during a hot, dry summer, with no supply of moisture available, will probably be found covered with a network of innumerable hair-like cracks, which are signs of the beginning of disintegration, the natural and inevitable result of the loss of the water of hydration of the cement." (Heath's "Manual of Lime and Cement," page 75.)

The only neat briquettes which were not cracked by the heat were some very old ones, about four years old, which were tested. Most of these were uncracked, although some that were very suddenly heated cracked somewhat. All the newer briquettes cracked, the cracks being very large in most cases.

After cooling, the briquettes were found to be quite soft, and could easily be crushed between the fingers. This was especially noticeable in the case of those briquettes which had lost the most water of hydration. These briquettes were like lumps of dry mud or clay, and a very slight pressure was sufficient to crush them completely. Briquettes which had not lost so much water were harder, while those which had lost only about one or two per cent. of water were quite hard. Of this latter class, however, those briquettes which had been heated suddenly were much the softer.

Briquettes which were cracked on removing from the furnace showed the cracks much distended and widened out on cooling, and most of those which had not cracked in the furnace showed cracks on standing for a day or two.

All sand briquettes, whether cracked in the furnace or not, entirely disintegrated on standing in air for a time, the cementing material having been entirely destroyed. Those sand briquettes which had lost most of their water of hydration disintegrated first, and those that had lost less followed soon after. Six briquettes of two sand to one cement were placed suddenly in the most intense heat, and left for about three minutes and removed. They lost from three to four per cent. in weight, and two of them which were broken showed a complete loss of tensile strength; one breaking before any load was applied, and the other going at about eight pounds. The remaining four were set away, and in a couple of days commenced to crumble, the edges going first, and leaving an irregular mass in the centre. This, however, resisted for some time, but in about three weeks they also were completely disintegrated. It was thought that the sudden application of very intense heat would cause the water of hydration to be removed from the outside only, and that the inside would remain solid, and resist weathering. The results, however, showed that although the outer part of the briquettes suffered most, as is shown by the rapid disintegration, still the heat also affected the inner part, and caused its ultimate disintegration. These briquettes were too hot to be handled comfortably when weighed, after removal from the furnace, and it is quite probable that the heat still remaining in the outer portion caused a still further loss of water of hydration in the parts in the centre of the mass. The low tensile strength of these two briquettes was probably caused by the sudden heat causing great internal stresses in the briquettes. The parts of the two broken briquettes also behaved in the same manner as the unbroken ones.

A number of briquettes were heated, and rapidly cooled by being immersed in cold water, after being heated for different lengths of time at different temperatures. In every case the briquettes cracked when immersed; and, if they were red-hot before immersion, they completely disintegrated—in most cases being reduced to a heap of soft mud. The sand briquettes acted precisely similarly to the neat ones; and it appears conclusive that if cement or concrete is allowed to become red-hot, and is then immersed in cold water, the effect would be ruinous in the extreme. Some briquettes were also heated, and, instead of being immersed, were placed under a small stream of water flowing at the rate of about two litres a minute. The results were the same. Red-hot cement completely disintegrated. In some cases, when heat had not been applied sufficiently long to heat the briquette through and through, and where the edges only glowed, the glowing parts chipped off when water was applied, leaving an irregular mass comprising that part of the briquette which had not been heated so much. Even when not completely disintegrated, this central mass showed cracks, was very soft, and had no strength to resist any pressure.

From these experiments, then, the following conclusions may be drawn :

(1) While there is no doubt that a covering of Portland cement concrete will afford some protection to a metal column or girder, still there appears to be no doubt that the concrete itself will be ruined by the action of the fire, and will have to be removed as soon as the fire is subdued. The concrete covering may remain upon the ironwork during a fire, but the heat will damage it to such an extent that it will disintegrate afterwards. The impression appears to exist that the concrete will be in as good condition after a fire as before. This is a mistake, as a fire of ordinary intensity is sufficient to ruin, completely, a very large covering of concrete.

(2) The concrete covering, if heated, will not stand the action of water; all the experiments show that water applied to hot cement is extremely ruinous. This is a very important point, when we come to consider the immense amount of water thrown into a building during a conflagration. The cement is certain to become red-hot ; and then, when the hose is turned on, the water strikes the protecting covering, and it breaks off, leaving the ironwork bare and filling the air with a shower of dangerous falling pieces. In a fireproofed building, the usual construction is to have a system of concrete arches and slabs between the joists and girders. The walls are of concrete, and have metal doors to confine the fire, if started, to one spot as much as possible. The floor is usually cemented over, or boarded with thin flooring, and is, therefore, more or less water-tight. The ceiling, or under part, might be exposed to intense heat, while immense quantities of water were being poured upon the upper portion, causing an immense strain on the concrete, not only from the

weight of water, but from the opposite strains which the cement would undergo, on account of one side being expanded by the intense heat, while the other side is kept cold by the water upon it. All this time the fire below is eating away the strength of the cement, and a collapse is the result.

(3) In calculating for the design of the columns and girders, and especially for floors, no allowance should be made for the strength of the concrete, but the cement covering should be considered as so much extra load on the system. It is the usual custom, in designing a fireproof system, to consider that the concrete bears its share of the loads upon the girder; and, in a great many cases, the girder is designed on that assumption. If no fire occurs, this is all right; but, during a severe fire, the concrete loses its cohesive properties, both on account of the loss of its water of hydration, and on account of the great internal strains caused by the expansion of one side under heat, and, consequently, becomes unable to resist any stress anywhere near what it was originally able to bear, and in most cases would not even be self-supporting. The experiments have shown that sudden heating is extremely ruinous, much more so than heat gradually applied; and, in the average fire, a very high temperature is generated in an incredibly short time, and concrete subjected to its action would, in a very short time, be unable to bear any strain whatever.

It appears from this that, in a fireproof building, floors should never be constructed of slabs of cement, forming short spans or arches from girder to girder, without any support. If no load were placed on the floor, and it were subjected to heat, it might possibly retain its form, provided water was not thrown upon it; but if loaded, as any floor would be, a collapse is inevitable. Concrete, then, should always have a metal system of some sort imbedded in it, sufficiently to bear the weight of the concrete itself, and all external loads which may come upon it.

The great advantages possessed by cement or concrete, as a fire-protecting material, are its low heat-conducting power and its very small expansion under heat. These advantages, however, are entirely off-set by the fact that it loses its strength under heat, is ruined by water applied during a fire, and will disintegrate after a fire, if not during the fire itself. These experiments tend to show, therefore, that the value of concrete as a fire-protecting material has been greatly overestimated, and that disastrous results may follow from confidence in a building protected with such a material.

TABLE I.—RESULTS OF 26 BRIQUETTES HEATED SUDDENLY.

Temperature, 1775° Fah. (approx.).

Weight in Grammes.		Per Cent. Lost.	Tensile Strength.		Per Cent. Lost.
Before.	After.		Before.	After.	
*140.02	125.57	10.4	530	190	64.1
*139.28	117.47	15.4	"	200	62.3
*140.06	115.75	17.3	"	185	65.1
*139.07	113.72	18.6	"	53	90.0
*140.46	125.99	11.6	"	180	66.1
*140.98	132.87	5.7	"	235	55.7
*139.23	137.68	1.1	"	330	37.7
*140.11	120.89	13.7	"	140	73.6
*139.47	133.57	2.9	"	280	47.1
*139.21	112.07	19.5	"	15	97.1
*140.17	121.17	13.4	"	155	70.7
*138.71	119.70	13.7	"	145	72.7
*135.77	131.70	2.9	930	0	100.0
†133.75	118.85	11.1	"	20	97.8
†132.75	dropped from tongs, and broke on floor.				
†131.16	123.05	6.2	930	50	94.6
†132.76	118.95	10.4	"	20	97.8
†134.15	128.70	4.8	"	23	97.5
‡139.22	125.72	9.7	515	85	83.5
‡138.41	128.39	7.2	"	75	85.4
‡140.00	134.23	4.1	"	122	76.3
‡137.35	135.54	1.3	"	200	61.2
‡138.47	131.38	5.1	"	97	81.1
‡138.21	135.68	1.8	"	185	64.1
‡140.04	112.87	19.4	"	0	100.0
‡137.26	113.24	17.5	"	10	98.1

* "Star" Brand.

† Briquettes, 4 years old, brand unknown.

‡ "Jossen" Brand.

TABLE II.—RESULTS OF TWENTY-ONE BRIQUETTES HEATED VERY GRADUALLY AND BROKEN.

Maximum Temperature, 1000°—1025° Fah.

Weight in Grammes.		Per Cent. Lost.	Tensile Strength.		Per Cent. Lost.
Before.	After.		Before.	After.	
*139.27	132.34	4.9	530	395	25.6
*138.31	130.16	5.9	"	390	26.3
*140.26	128.32	8.5	"	348	34.3
*140.06	129.16	7.8	"	351	33.7
*138.07	126.23	8.6	"	327	38.2
*138.04	120.13	12.9	"	152	71.2
*139.26	116.27	16.5	"	73	84.3
*138.35	113.31	18.1	"	29	94.5
*140.21	119.26	14.9	"	110	79.0
*139.32	125.34	10.04	"	237	55.2
†137.79	129.32	6.1	515	348	32.3
†139.42	130.26	6.6	"	348	32.3
†140.31	133.58	4.8	"	398	22.6
†139.27	127.31	9.3	"	232	49.0
†140.32	120.15	14.3	"	182	64.7
†138.37	136.32	1.5	"	440	14.7
†139.46	134.31	3.7	"	400	22.3
†140.07	121.31	13.4	"	195	62.3
†139.36	117.26	15.8	"	130	74.6
†140.21	122.31	12.5	"	193	62.4
†139.36	112.60	19.2	"	10	98.0

* "Star" Brand.

† "Jossen" Brand.

ASPECT AND PROSPECT

C. H. C. Wright, B.A.Sc.,
Lecturer in Architecture, School of Practical Science.

In addition to providing the necessary accommodation in a dwelling, an architect must also satisfy the convenience of his client, as far as possible, by a suitable arrangement of halls and rooms, and at the same time make the different rooms in the residence as cheerful and pleasant as possible.

Among the many features which contribute towards making the home cheerful and pleasant, the two most important, and at the same time most neglected in Ontario, are the relation of the building, or rather of the different rooms, to the position of the sun, *i.e*, aspect; and, secondly, the placing of the windows to take advantage of the pleasant views of the landscape, and at the same time obstructing any undesirable views.

The aspect of a room, then, is the relation of its windows to sunlight and weather, while the prospect is simply the view from the windows.

A landscape, as seen from the southern windows, will, with the exception of the early morning and evening of the longer days of summer, appear dark, with the shady side of all objects facing the observer; while the western prospect will be well lighted in the morning, the eastern prospect dark, but lighted in the afternoon, and the northern well lighted at all times, in the morning and evening from the side, thus casting, in most cases, pleasing shadows.

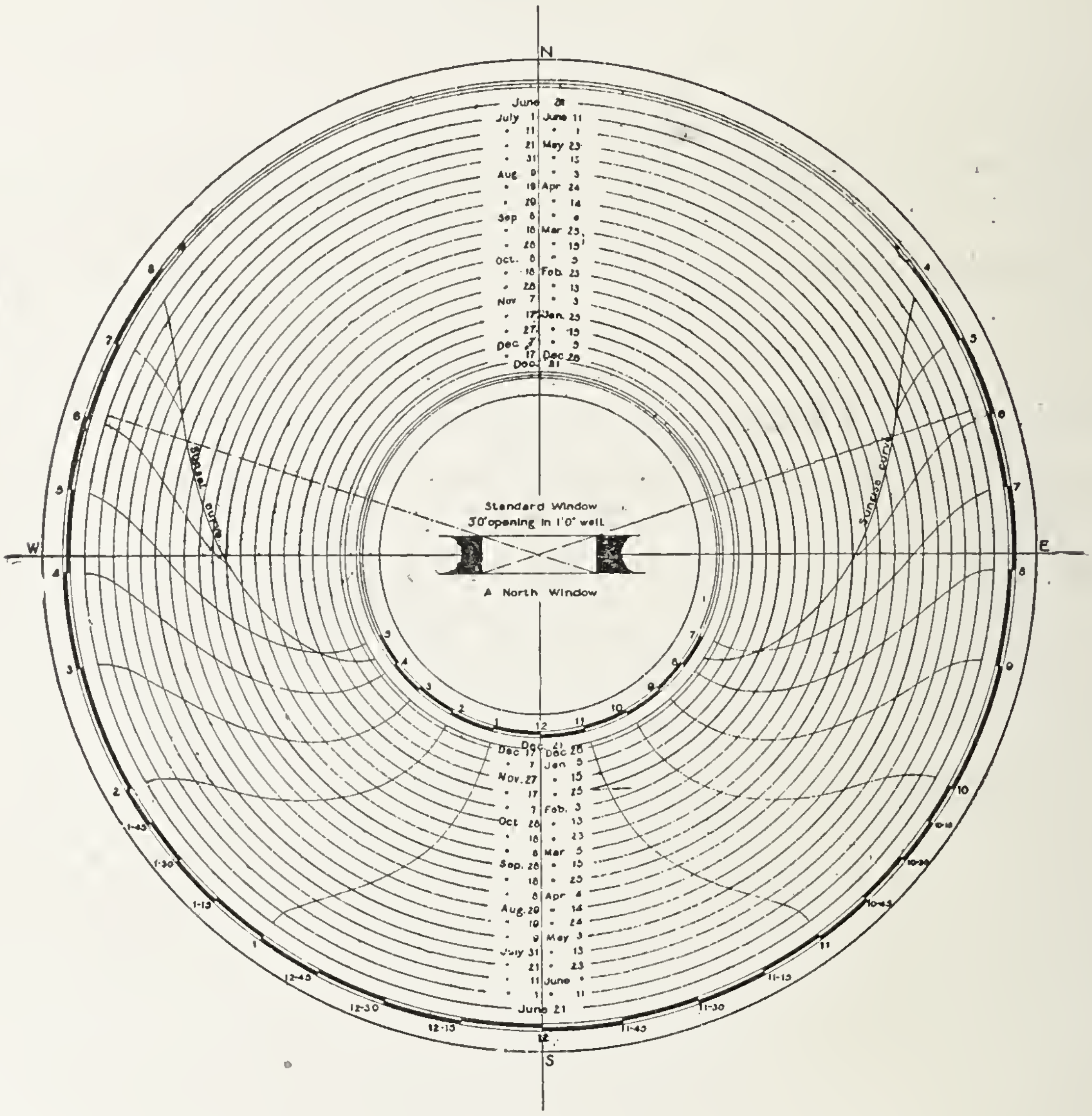
In the cities and larger towns our architects say, "If we only had the landscapes"; while in our rural districts we meet with the fact, if not with the statement, that our dwellings must have their axes parallel, or at right angles to the road, with the parlor on one side of the entrance and a sitting-room on the other, irrespective of what the landscape may be, or whether the road runs north, east, or towards any other possible point of the compass. If the planning of our townships had depended upon the contour of the country, so that the roads would wind back and forth up the valleys, the result of placing the rural residences in some regular way from them might have been satisfactory. But, unfortunately, surveyors, acting upon instructions from the Government, have followed the straight and narrow way over hill after hill. Even on many of the through roads the principle of laying out seems to have been Euclid's definition of a straight line, with an utter forgetfulness of the conservation of energy. In this connection there is no doubt that a vast improvement is possible throughout the country, and much might be accomplished, even in the cities and towns, by obstructing an undesirable view with a group of cool spruce trees, or a cluster of birch with their delicate green foliage and brilliant white bark, assisted, perhaps, by a few flowering shrubs. While there may be some reason in the excuse that a landscape cannot be provided in every case, yet there is no reason for the haphazard position of the rooms and windows, relative to sunlight, which is exhibited throughout the province.

In the cities and towns it is not possible to have all of the houses on the north or west sides of the streets. Much might be accomplished, however, if a little judicious care were taken in providing bay windows, prejections, etc., and even in the proper location of the windows in the different rooms. In many cases the living rooms of the house might be placed at the garden front with good results. There are, throughout the province, a few cases where this has been done, much to the satisfaction of the occupants of the house. In this connection might be mentioned the residence, in Galt, of the Hon. James Young, which is placed with its back to the main street, thus throwing the living rooms on the garden front, and giving at the same time a southern aspect, and a magnificent view up the ravine. On the other hand, there are, in the neighborhood of the Bay of Quinte, a number of pleasant country villas, situated on rising ground and commanding magnificent views of the beautiful Napanee valley and the blue, sparkling waters of the bay, bounded in the distance by the shady groves and bright meadows of Prince Edward County; and yet these houses are placed without any feeling whatever for their sublime surroundings, without any regard to the daily journey of the sun, and the direction of the cutting winds or pelting rains, but simply situated on rising ground, with their axes parallel with concession —— of township ————.

A guest at such a house, where everything might and should be properly arranged, is ushered into a cool drawing-room, with a poor prospect, and partakes of an evening meal with the bright sunlight glaring in his face; when, if the plan had been reversed, he would have enjoyed the dining-room because of its coolness, and the drawing-room would have been cheerful on account of the sunlight.

Why, in Ontario, we have been careless of such matters, when a little trouble would conduce to such comfort, it is difficult to say; but, judging from the results of our best architects, there will be a decided improvement in the near future.

Professor Kerr, in his exhaustive treatise on house planning, publishes, among the many illustrations, a diagram which he called an aspect compass, and which simplifies very materially the question of determining the available sunlight.



In the annexed diagram the position of the sun is given for any time of the year, for any place in the latitude of Toronto. Apparent time has been used, so that a correction must be made, first for mean time, and afterwards for standard time, if necessary. It will be readily seen from this illustration that, while the sun is due south at noon, its direction is not constant for any other hour during the year, but varies, moving along a reversed curve as indicated. Thus, while the sun may be slightly north of east at 7 a.m., on the 22nd of June, it is considerably south of east in midwinter, and for intermediate dates the direction of the sun may be found by observing the intersection of the 7 o'clock curve, and the circle representing the required date.

The 5 o'clock curve ends when the sun rises at 5 o'clock, the 6 o'clock curve when it rises at 6 o'clock; so that, in joining these points, we get a curve of sunrise, and similarly for sunset. On the diagram the azimuth of the sun is not shown before sunrise or after sunset, as it would not be of any value for the purposes of aspect.

In using this diagram, all that is necessary is to apply a tracing of it to the plan of the proposed house, shifting it from one window to the next, being careful in each case to keep the centre of the diagram in the centre of the opening, and the proper direction of the meridian.

The diagram indicates the application to a window in a north wall, and shows that the sun's rays may enter such a window from April 25th until August 18th, and that there will be one-and-a-half hours of sunlight entering in the morning of June 21st, the same in the evening, while from August 18th to April 25th there will not be any direct light coming through the window.

Considering this window to be in a south wall, sunlight would enter from 9.15 until 2.45 on June 21st, or from 8 o'clock until 4 o'clock on April 2nd. Similarly, the amount of available sunlight may be determined for any given position of the window. It will thus be seen that a southerly window gives a maximum of sunlight, when the rays have their greatest hygienic value.

For the benefit of those members of the society who have not given much thought to the aspect of different rooms, it might briefly be stated that a dining-room should have a north or northeast aspect. A combined dining and sitting room must have a compromised aspect, depending largely upon the character of the household, the style of living, and local peculiarities. In the case of a morning room (used for breakfast and a morning sitting-room), the morning sunlight will always be welcome, and an eastern or southeast aspect is desirable.

The drawing-room should have such an aspect as will give a maximum of sunshine and mild weather, avoiding, as far as possible, the disagreeable east winds, wet weather, and sultry sunshine.

LAING'S PLANETARIUM

By A. T. Laing, B.A.Sc.

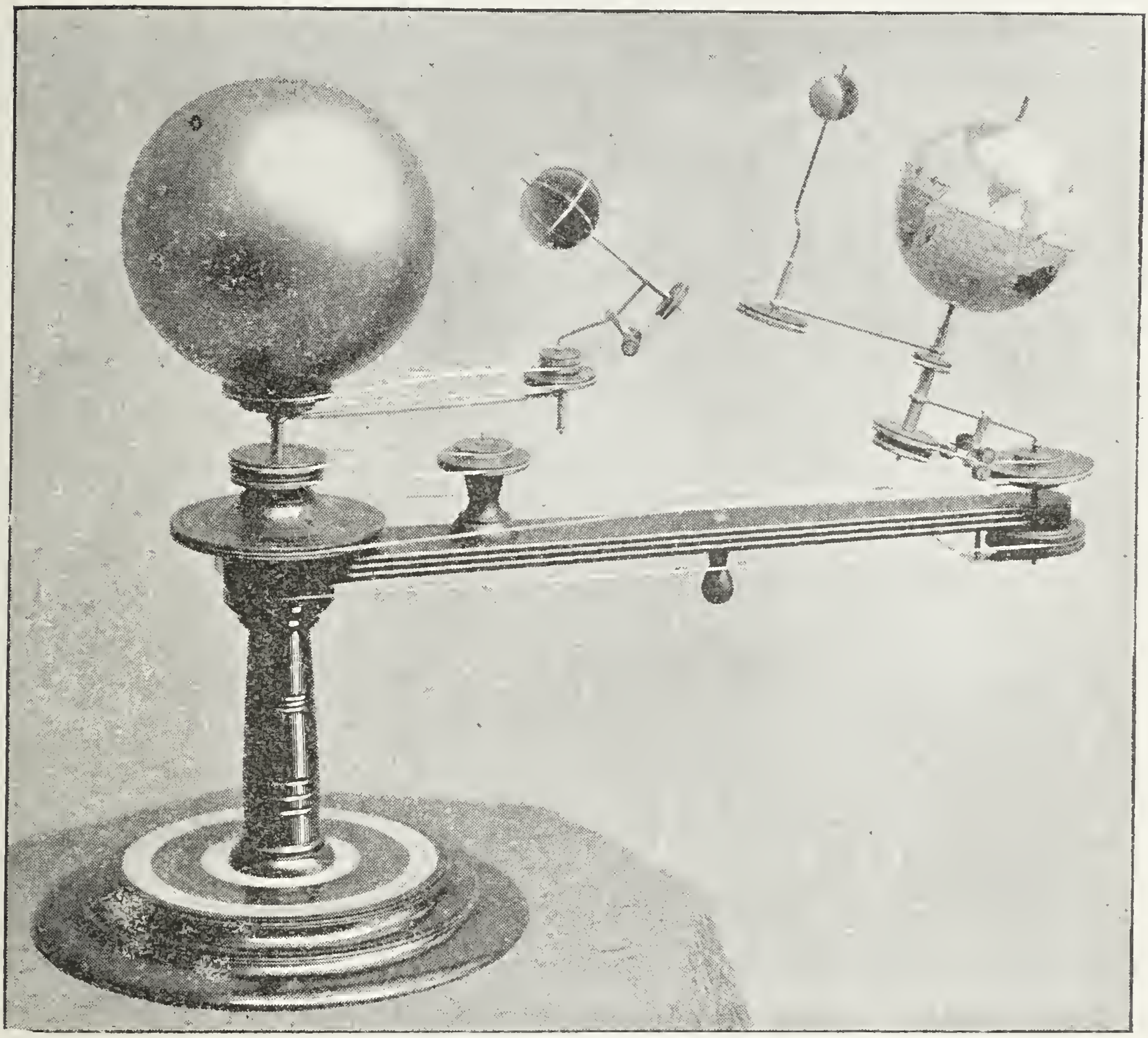
It is with pleasure that I present to you, this afternoon, this recent invention, called after the inventor, Mr. A. Laing, of Essex, Ont., "Laing's Planetarium." It is one of the most complete of astronomical instruments that has ever been constructed for the elucidation of planetary phenomena.

It is designed principally for use in the various educational institutions of the country, and has already met with the highest approval by many who stand at the head of these institutions. It will prove of invaluable assistance to the teacher in attempting to teach mathematical geography, as well as primary and advanced astronomy. Besides its use in schools, this instrument will make a handsome and instructive addition to the equipment of any private library. It will stimulate in the minds of those who study it a taste for the subjects which it illustrates and explains; and when an interest in the subject of astronomy is awakened, it develops a spirit of research and enquiry, which the instrument will do much to gratify.

The following are a few of the many facts plainly illustrated by the instrument:

I. It shows that the diurnal rotation of the earth is the cause of the apparent diurnal motion of the sun, moon, and stars from east to west, in consequence of which they rise in the east and set in the west, thus clearly showing the cause of day and night.

II. It shows also, very clearly, that the sun crosses the equator from south to north on the 20th of March, or the time of the vernal equinox; and that, as the sun moves along the great circle of the ecliptic, it reaches its greatest northern declination perpendicular to the tropic of Cancer, 23½° from the equator, about the 21st of June, or the time of the summer solstice; and that then the great day star inclines its course toward the south, crossing the equator at a point diametrically opposite the vernal equinox. The sun still continues its course toward the south, till it reaches its greatest southern declination about the 21st of December, or winter solstice, perpendicular to the tropic of Capricorn, 23½° south of the equator; and that the sun then begins to incline its course toward the north, reaching the vernal equinox again on the 20th of March in the following year, having made a complete circle of the ecliptic.



LAING'S PLANETARIUM.

This illustrates the four cardinal points of the earth's annual motion—the vernal equinox, summer solstice, autumnal equinox, and winter solstice.

III. The axis of the earth is very plainly shown to be pointing in the same direction, or toward the pole star, at an inclination of 23½° from the perpendicular, during its complete circuit around the sun, thus illustrating the vicissitudes of the seasons and the changing of the climate.

IV. The instrument clearly illustrates the fact that the circle of illumination is perpendicular to the ecliptic, and at right angles to the radius vector; and that, at the time of the equinoxes, the circle of illumination cuts all the parallels of latitude as well as the equator in two points, diametrically opposite, thus giving equal day and night all over the world; while, at the time of the summer solstice, this circle cuts the earth at a point 23½° beyond the north pole, and falls short of the south pole by the same distance. This produces a difference in the duration of day and night, which depends upon the parallel of latitude in which we live.

The pamphlet of instructions which accompanies the instrument gives a table of the lengths of day and night, according to the latitude, from the equator to the polar circles.

V. The fact that the ebb and flow of the tides does not occur at the same time each day is very clearly explained by using this instrument. It shows the cause of the difference to be the motion of the moon around the earth, in the same direction that the earth rotates.

VI. The planetarium plainly shows that the orbit of the moon cuts the plane of the ecliptic at an acute angle, thus illustrating what is meant by the ascending and descending nodes.

VII. The apogee and perigee of the lunar orb are shown so clearly that a child can understand it.

VIII. It clearly demonstrates the fact that an eclipse of the sun can take place only at the epoch of the new moon, and that the moon can undergo an eclipse only when it is full. It also shows that on account of the inclination of the moon's orbit, already referred to, it is only when at the moment of new or full moon, the moon is at or near its node, that an eclipse can occur. This gives the reason why we do not have eclipses every month.

IX. The three principal motions of the planets are nicely illustrated. They are as follows: When a planet is seen to be travelling from west to east among the stars in the celestial sphere, it is said at this time to have its direct motion; but when its motion appears to be from east to west, it is called its retrograde motion. And during the periods between the direct and retrograde motions the planets will for a short time appear stationary. The instrument shows the cause of these apparent motions to be due to the manner in which the orbital motions of the planets are combined with ours.

X. The instrument illustrates the fact that the orbital motion of Venus is so combined with ours that it causes her to return to the point of inferior conjunction every 584 days, and when she passes this point out to the right or west of the sun she is called our morning star. She wings her flight out to the point of greatest western elongation, and passes round to the point of superior conjunction, when she ceases to be morning star and assumes the office of evening star; she now passes out to the left or east of the sun and becomes higher and brighter till she passes her greatest eastern elongation. She now pursues her course till she reaches again the point of inferior conjunction, and becomes our morning star once more; and, as is shown by the instrument, these aspects are repeated in never-ending succession.

Very nearly the same remarks will apply to Mercury, the periods of time being different. The transits of Venus and Mercury are explained at the same time.

XI. The perihelion and aphelion of the Earth, Jupiter, or any of the primary planets, is made very clear by the use of the instrument.

XII. It also shows in a comprehensive manner what is meant by the zodiac; how it is divided into twelve signs, and the names of the signs. What is meant by right ascension; how that the sun, for instance, is said to be in six hours right ascension at the moment of the June solstice (or the moment when the sun enters the sign of the zodiac called Cancer), the sun at the same time having reached its greatest northern declination; how the sun is said to be in twelve hours right ascension at the time of the autumnal equinox, its declination at the same time being zero; also how the sun is in eighteen hours right ascension at the time of the winter solstice, and how, at the same time, the sun enters the sign Capricornus, 23½° south declination. Also that the sun's right ascension and declination are both zero at the vernal equinox.

Besides what is contained in the brief remarks above, the following are some additional facts illustrated by the instrument: The ecliptic, the zones, the midnight sun, the seasons of Venus, leap year, the procession of the equinoxes, parallelism of the axis of Venus, the continual changing of the amplitude of the sun, etc.

One of the main features of this instrument is its simplicity of construction; there is nothing to get out of order, and all the various motions go on simultaneously.

ROENTGEN RADIATION

By J. C. McLennan, B.A.,
Assistant Demonstrator in Physics at Toronto University.

When the announcement was recently made by Professor Roentgen, of Wurzburg, Germany, that he had discovered a new kind of radiation, it excited so much popular interest, and seemed to have such a far-reaching influence in the development of physical science, that we considered it advisable to verify in Toronto at once, as far as practicable, the results obtained by the original investigator

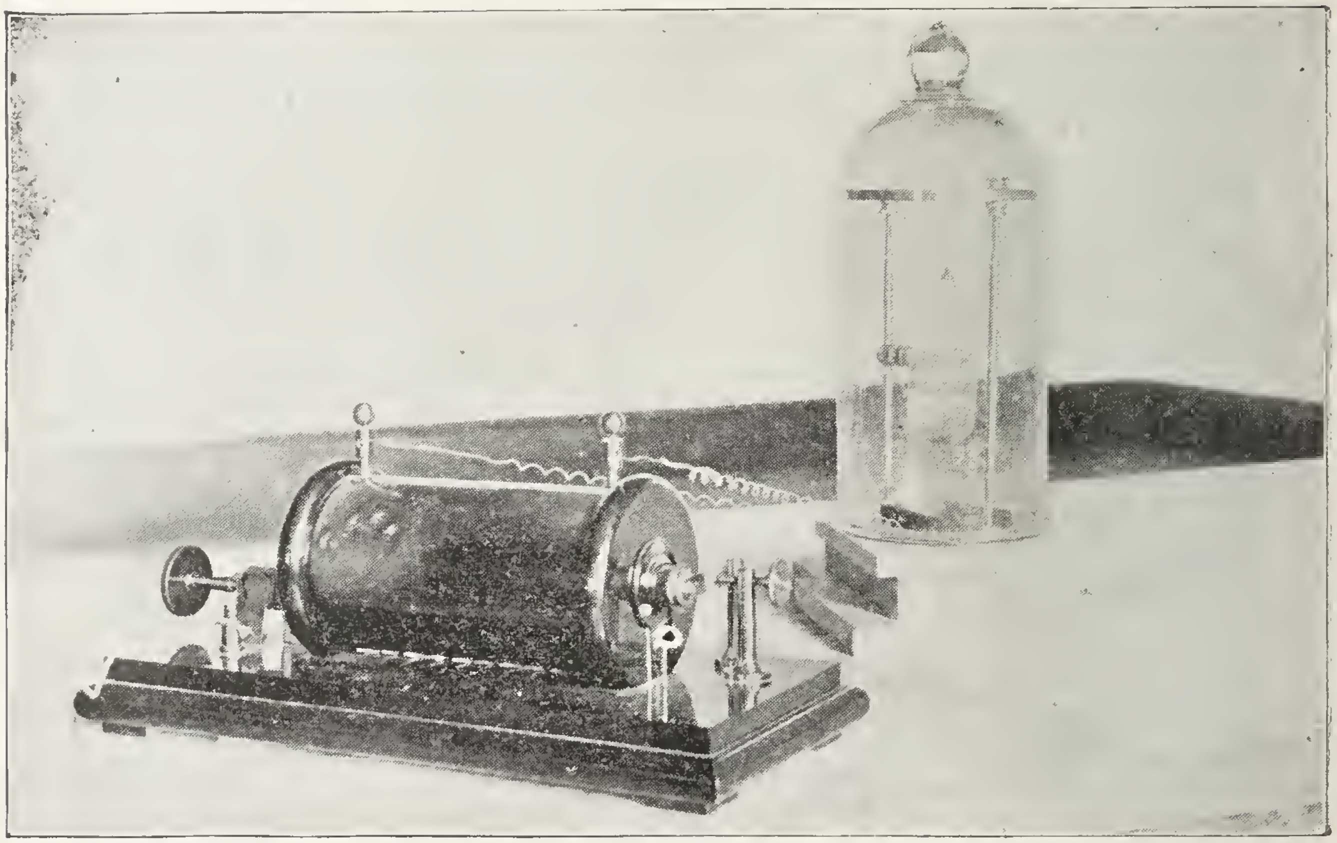


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FIG. I.

Apparatus showing Induction Coil and Bell-Jar containing Crookes' Tube.

Together with Mr. C. H. C. Wright, B.A.Sc., Lecturer in the School of Practical Science, and Mr. J. Keele, B.A.Sc., of the same institution, the writer repeated these experiments, and found the results exactly as described, and even more wonderful than we had anticipated.

As shown in the accompanying illustration, the apparatus used by us consisted of an induction coil of moderate size and a Crookes' tube of special form.

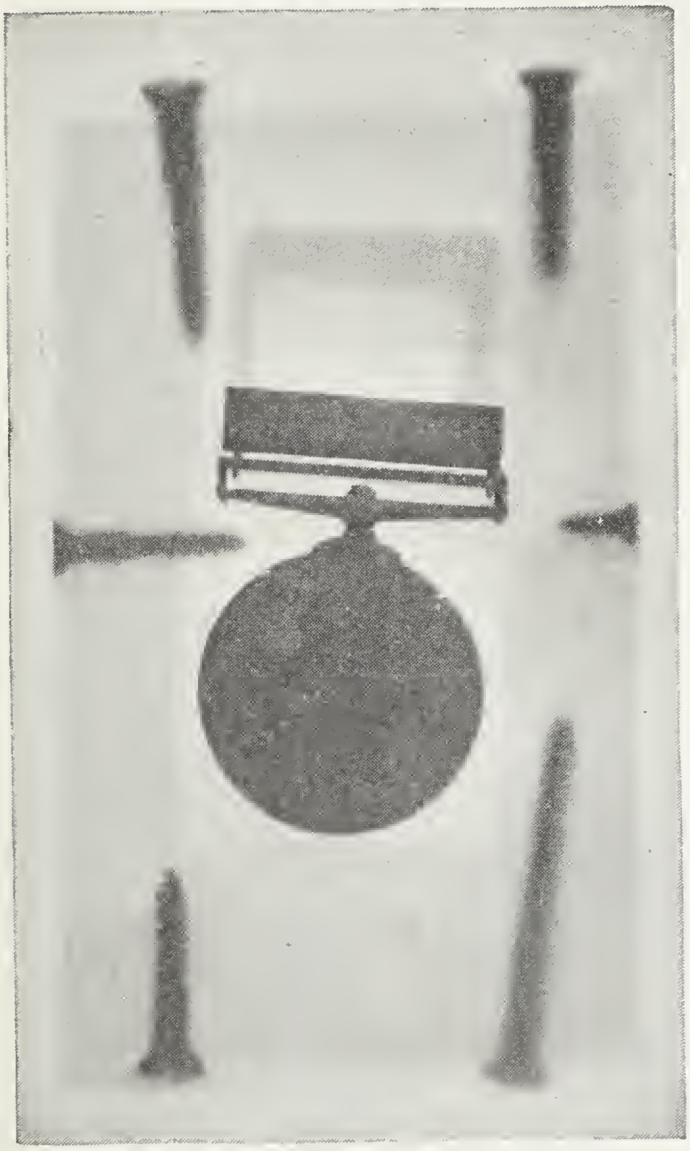

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FIG. II.

Northwest Medal Photographed through a Block of Wood.

Crookes' tubes are made of glass, and were originally designed to exhibit properties of the electric discharge when passed through air at different pressures. The electric current is led into and from them by means of platinum electrodes sealed into the glass and carrying discs or caps of aluminium of different shapes to give variation to the form of the discharge.

When an electric spark is passed through a tube from which the air is being gradually exhausted, it presents a variety of appearances, each being characteristic of the vacuum obtained. At first it consists of a single line of light. It then breaks up into a number of irregular streaks, and this appearance, as the exhaustion goes on, gives place to a bluish colored halo between the electrodes. This halo then breaks up into a series of parallel discs, and, on pushing the exhaustion still further, these disappear entirely from the negative, but remain in the region of the positive electrode. Here a new appearance is presented. When the air has been exhausted to this degree, the part of the tube directly opposite the negative electrode begins to glow with a beautiful fluorescence, which indicates that some peculiar invisible discharge, causing this effect, is emanating from the negative electrode. It is the cathode rays, so called, which are said to form this discharge, and the tube in this condition constitutes a Crookes' tube.

These cathode rays have been very fully investigated by Lenard, Hertz, Thomson, and others. It is found that, like ordinary light rays, they travel in straight lines, are capable of producing intense heat; and, unless especial care is taken, there is great danger of melting the tube if the discharge is continued without interruption, even for a few minutes.

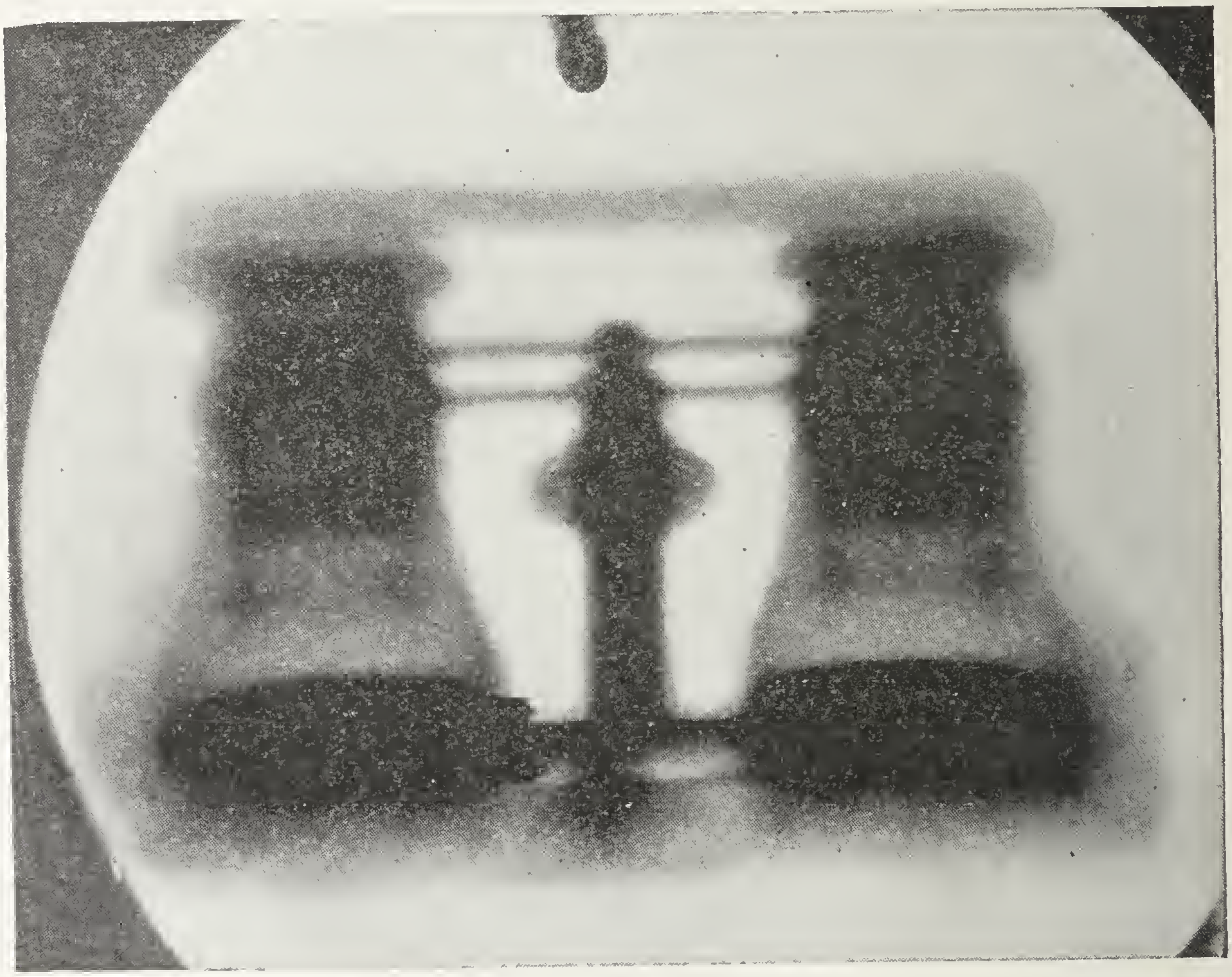

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FIG. III.

Opera Glasses Photographed Through Case.

If a magnet is brought up to the tube when these rays are passing, they can be readily deflected from their direct path, and, in fact, a finger presented to the tube is sufficient to deflect them towards the point of contact.

In his early experiments, Professor Roentgen found that on surrounding a Crookes' tube while in action with a close-fitting black paper cover, it was possible to see in a completely darkened room a brilliant fluorescence upon paper covered with barium platino-cyanide held near the tube. This appearance he found to be still visible, though faint, at a distance of two metres. From this experiment he concluded that the Crookes' tube was the origin of the action causing the fluorescence, and that this action, whatever it was, passed through paper which was impervious to ordinary light. Extending his experiments by placing other substances between the Crookes' tube and the fluorescent screen, he found that all bodies allowed this new kind of radiation to pass through them in a greater or less degree. Wood, paper, and water were very transparent, aluminium and ebonite fairly so, while copper, lead, gold, platinum, and even glass were quite opaque unless made in very thin plates. Different thicknesses of various materials were tried, and the results obtained showed that as the thickness increased the hindrance offered to the new rays by all bodies also increased.

The density of bodies seems to be the only property which affects their permeability, and yet their densities alone do not determine completely their transparency, as plates of aluminium, glass, quartz and Iceland spar of equal thickness were interposed between the tube and the screen, and it was quite evident that, although their densities are about the same, the resistances they offered to the passage of the rays were quite different. Although these new rays can be passed through many substances which are opaque to sunlight, no evidence has yet been obtained which would show that they can be refracted. On passing them through prisms, or lenses, of water, carbon bisulphide, ebonite, aluminium or wood, there is no indication, or, if any, but slight, of refraction at these surfaces.

Since many metals and glass of ordinary thickness are found to be impermeable to these rays, it is but natural to expect that these substances would reflect them; but all experiments so far seem to show that the ordinary law of reflection does not hold for these new rays, and that if they can be reflected at all it is only in a very general and irregular manner.

Although this unknown radiation was at first detected and studied by means of a fluorescent screen, it was soon found that ordinary photographic dry plates were sensitive to it, and it is owing to the developments in this direction that such intense interest has been aroused.

The reproductions illustrating this article are from photographs taken in the course of our own investigations, and they will indicate some of the possibilities of the new discovery. Fig. II. was obtained by placing on the cardboard box containing the sensitized plate a silver medal, over which was placed a block of wood one inch thick. The screws also shown in the picture were driven into the wood, and from the appearance of the

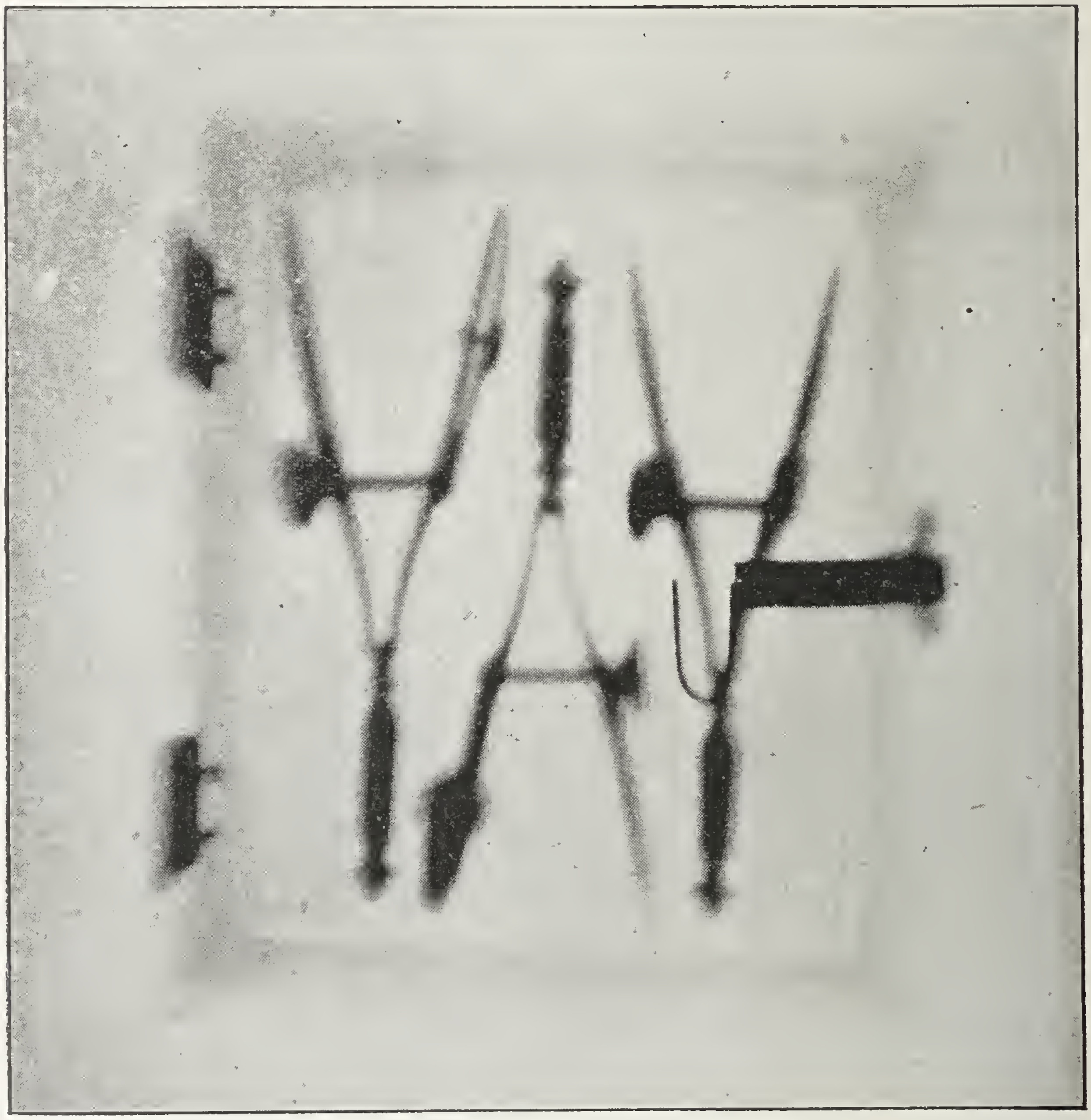


FIG. IV.
Instruments Photographea Through Case.

cut it is quite evident that while the wood offered but little resistance to the passage of the rays the metals were quite opaque. Fig. III. represents a pair of opera glasses taken in their case. The metal parts were of aluminium, and it can be seen that, while the rays passed through the tubes at all points, they did so to a much greater extent where there was only one thickness of the metal. The object lenses are clearly defined, showing that the glass is quite opaque, and the outlines of the case are indicated but faintly. Fig. IV. shows a set of drawing instru ments inclosed in a thick leather case.

The action upon the sensitized film of the dry plate seems to be the same as that due to the light of the sun. The developers used were metol, hydroquinone, pyrogallic acid, and oxalate of potash and iron. Pyro' developer seemed to give best results. The images came up rather more slowly than with ordinary light, and the density as seen before fixing the plate was somewhat misleading, as the chemical action seems to be confined to the surface of the film only. The color of the deposit upon the plate by the various developers is the same as that given by sun light Various types of dry plates were tested, but, though we were unable to detect any difference in the action upon them, it may be possible, when more properties of the new radiation are known, to produce a more sensitive film than those now in use.

During our early experiments we found that the time required to obtain good impressions on a plate was so long that the utility of the new discovery seemed to be very limited, even if not doubtful.

We therefore directed our efforts to reducing, if possible, the time of exposure, and this we succeeded in doing to a very marked degree.

On making a careful test of all the tubes in the Physical Laboratory, we found one which gave a much stronger radiation than any of the others. This tube, constructed by Seguy, of Paris, was pear-shaped, and as it had one electrode inserted in the smaller end, and the other in the side, we were able, by making the former the negative terminal, to obtain a large glass surface exposed to the action of the cathode rays. This tube was employed in all our later experiments. Thinking that probably the action would vary with different sensitized films, we conducted a series of tests to determine the relative sensitiveness to the rays of various types of plates, but observed no marked difference, and concluded that any reduction in the time of exposure must be otherwise obtained. As experiments made with prisms and lenses of wood, pitch, and other materials, gave no indication of refraction at their surfaces, the only remaining method for the concentration of the rays seemed to be an application of the principle of reflection. In order to determine whether the rays could be reflected, a surface of clean mercury was prepared, *and it was found that when the rays were directed towards this surface sensitized films protected from direct radiation were fogged by some action coming from the mercury. To test this apparent reflection still further, a sensitized film, protected by a plate-holder, was placed at a distance of about twenty centimetres below the Crookes' tube. A thick plate of glass was then inserted midway between the* *tube and the film, parallel with the latter, with the intention of screening the plate in part from the action of the rays. The tube was then excited for some time, and on developing the film it was found that the rays evidently travelled in straight lines, since the part of the film protected by the glass plate was well defined and entirely unaffected by them. This experiment was repeated, the arrangement of apparatus being identical, with the sole exception that a glass bell-jar was placed over the whole. Development of the film in this case showed (1) no action on the film outside the jar; (2) no indication that the interposed plate glass acted as a screen; (3) the action much more intense than in the previous experiment, proving conclusively the reflection of the rays from the surface of the jar.*

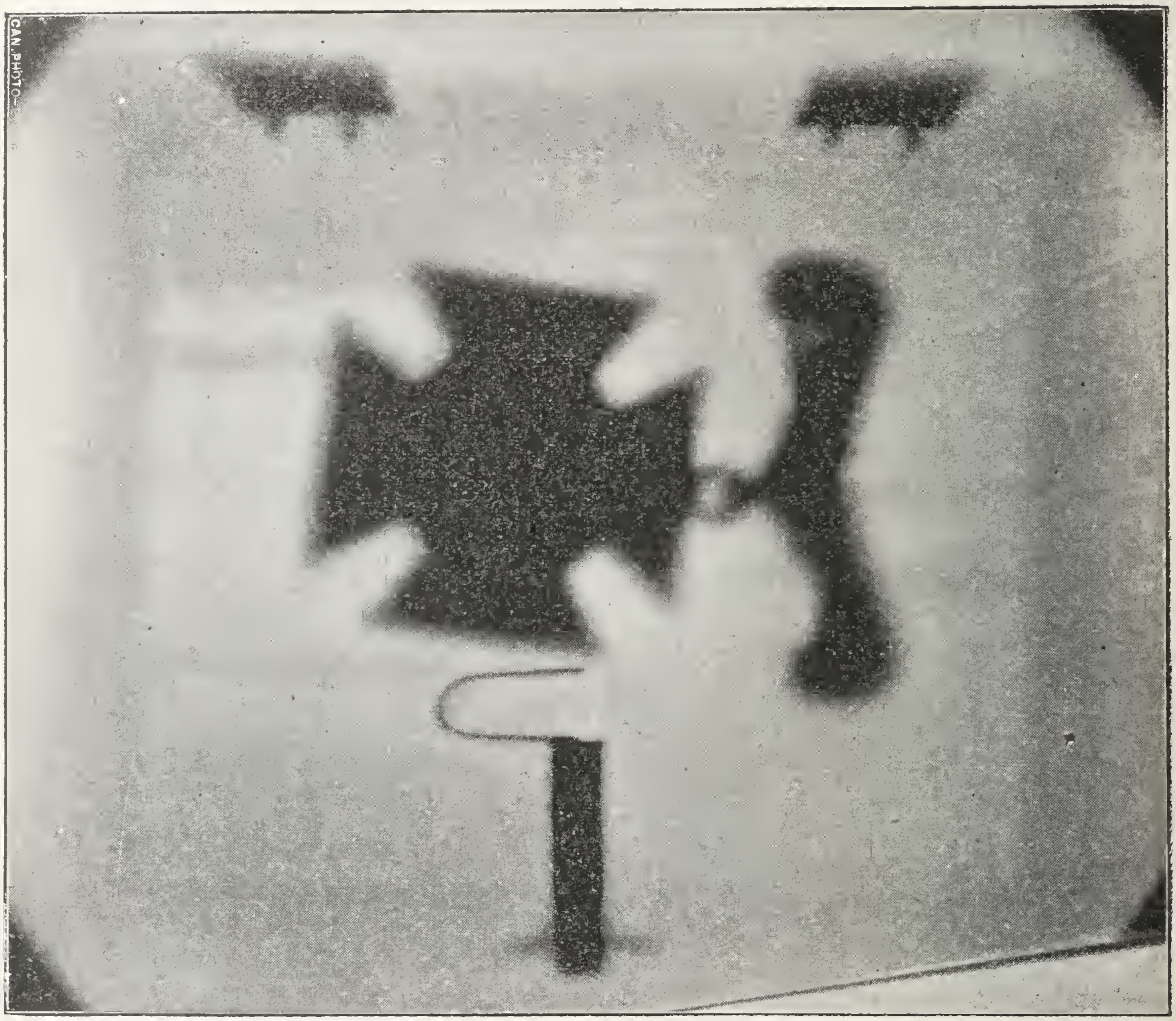


FIG. V.
Medal Photographed in its Case.

By the employment of this method we reduced on the 11th February the time of exposure almost to instantaneousness. The picture here given (Fig. V.) was taken with the bell-jar over the apparatus, and was obtained by an exposure of four and a half seconds, the object being a medal placed within a leather-covered wooden jewel case. Very good results were similarly obtained by an exposure of one second through five folds of black paper.

The importance of the new discovery in its application to surgery appears to be somewhat exaggerated. In detecting foreign bodies imbedded in animal tissue, much depends on the character of these bodies, and upon their particular location relative to the bones. In this connection it may be interesting to state that from a photograph of a patient's foot taken by us we located the point of a needle in it so accurately that the surgeon stated he was able by a single incision to remove it. As the needle in this case was situated between two of the bones, the conditions for obtaining a good shadow were rather favorable.

There have been many conjectures regarding the nature of this new radiation, but up to the present its true character remains quite uncertain. As already indicated, it does not pass through glass, and from this it has been concluded that although the cathode rays produce it, it is a form of radiation quite distinct from these rays. This conclusion is further confirmed by the fact that while cathode rays can be deflected from their direct course by a magnet, the latter has no effect on the radiation outside of the tube. It is generally conceded now that when the cathode rays strike upon the glass of the Crookes' tube, vibrations are set up in it which, on being communicated to the space outside, produce what we may now call the Roentgen rays. In fact, it seems to be proven conclusively that this view is the correct one, as Professor J. J. Thomson in his recent experiments found that a sensitized photographic plate placed *inside* a Crookes' tube in the path of the cathode rays was quite unaffected by them. Whether these rays are merely ultra-ultra violet rays, or whether they are due to vortex motions or to the longitudinal vibrations which are supposed to accompany the ordinary light vibrations in the ether, is a problem which has yet to be solved.

I cannot close this article without referring to the assistance given us by President Loudon, of the University of Toronto, and Professor Galbraith, Principal of the School of Practical Science. Much of the success which accompanied our experiments was due to the many valuable suggestions offered by them, and to their kindly placing at our disposal every facility which their laboratories could afford.

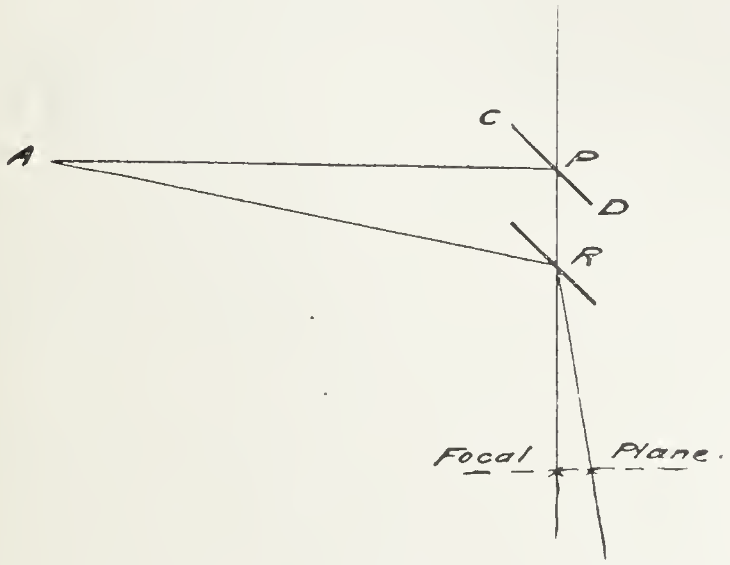
A SIMPLE FORM OF TELEMETER

By L. B. Stewart, D.T.S.,
Lecturer in Surveying, School of Practical Science.

The principle of the following simple form of telemeter occurred to the writer a few years ago, and an instrument constructed on that principle, in a preliminary trial, gave promise of such good results that a description of it is here given for the benefit of any who may have use for such an instrument. In facility of use it may not compare favorably with some telemeters used for military purposes, but in accuracy it is probably superior to some, and in portability it is all that could be desired.

The instrument consists of a small telescope, in front of the objective of which a triangular reflecting prism is mounted, with the reflecting surface at an angle of 45° with the axis of collimation of the telescope. The thickness of the prism is half the breadth of the objective, so that two images are formed at its focus, one that of an object situated on the axis of collimation produced, and the other formed by a pencil of rays which is bent through a right angle by the prism. It can be shown that if the two acute angles of the prism are equal, the direction of a ray of light after reflection and refraction by the prism is the same as if it had suffered no refraction. At the focus of the telescope are placed a number of equidistant parallel lines, like transit threads, and also a line cutting them at right angles; and by its intersection with the middle line defining the axis of collimation. Preferably, these should be lines etched on glass, on account of their permanency and the constancy of their intervals. They are placed so as to be parallel to the reflecting surface of the prism, and, moreover, they are adjusted so that when the instrument is set up at the vertex of a right angle, subtended by two points, they can both be made to appear on the middle line, one being seen directly and the other by reflection.

This completes the description of the instrument. In order to use it to obtain the distance to a distant point, such as A, set up the instrument on a tripod or other firm support at P, and turn the telescope until the point seen by reflection appears on the middle line ; at the same time observe directly some point, as B, that appears also in the centre line, or plant a picket at that point. The point P is marked on the ground. The observer then moves the instrument back along the line BP until some point R is reached, at which the point A appears by reflection on the first side thread, the telescope being directed along the line PB. The point R is also marked, and the distance PR measured. The distance AP may then be found by multiplying RP by a constant whose value depends on the focal length of the objective and the distance from the centre line to the line employed. A value of the distance AP may thus be found by means of each of the lines in the focus of the telescope.



It will be observed that the constants for the various lines diminish as their distances from the centre increase, and. therefore, as the corresponding points on the ground may be found with equal accuracy, the probable errors of the different determinations of the distance will be proportional to those constants, and their weights proportional to their inverse squares. In combining the measurements of the distance, each should therefore be multiplied by its weight and the sum of the products so formed divided by the sum of the weights. If the lines are sensibly equidistant, the weights of the determinations of a distance by the lines taken in order from the centre may be assumed to be the squares of the natural numbers 1, 2, 3, etc.

The constants of the instrument may be determined best by actual trial on measured distances. A good way to do this is to attach the instrument temporarily to a block which slides along a straight edge placed horizontally; the axis of collimation is adjusted parallel to the straight edge by so placing the instrument that some distant point remains on the central line, while the instrument is slid from one end of the straight edge to the other. Some well-defined object is then placed at a convenient distance off, at right angles to the direction of and in the same horizontal plane as the straight edge. A screen with a narrow vertical slit, behind which an illuminated white surface is placed, will answer this purpose well; the flame of a lantern is not as good on account of irradiation. The instrument is then shifted, bringing by reflection the image of the slit on each line in succession, and marking the corresponding point on the straight edge. The distance of the slit from the outer focus of the objective of the telescope is then measured, when the image of the slit is on the middle line, and the observer is then in possession of all the data necessary for the calculation of the constants. This operation may be carried on in any good-sized room, and a few determinations will give the values of the constants as accurately as can be desired.

Another necessary adjustment is to insure the parallelism of the lines and the reflecting surface of the prism. This may be done by placing the instrument in a horizontal position, bringing some point which is in the horizontal plane of the axis of collimation to the centre of the field of view by reflection, and then turning the diaphragm until the middle line coincides with a plumb line seen directly.

A few trials made with an instrument constructed for the writer leads to the conclusion that distances may easily be found with an error of less than one per cent., and possibly with a much smaller percentage of error by combining the results of all the lines.

BRICKWORK MASONRY

Results of tests made in the Laboratory of the School of Practical Science, Toronto, during the session of 1895-6, by Messrs. Wright and Keele.

By Jos. Keele, B.A.Sc.

BRICKWORK PIERS.

The following tests were made with the object of determining the resistance to crushing offered by piers of ordinary brick, constructed in the same manner and of the materials as those most commonly used in practice in Toronto. These materials will fairly represent those in use throughout the Province of Ontario.

For this purpose a bricklayer and his assistant were engaged to procure from four different brickyards a quantity of each of their grade of bricks, the bricks being taken from the kiln as they came to hand.

The different bricks used were Kingston Road, first, second, and third quality; Humber, first and second; Yorkville, first and second; Carleton clinker and first, and Don Valley pressed brick, buff and red.

An individual test of each class of brick was made to determine its crushing strength and absorption. The absorption test was made as follows: The dry brick was carefully weighed, then immersed in water, and at the end of twenty minutes the brick was taken out, the surface water dried off, and again weighed. The brick was again immersed until the total time of immersion was thirty minutes, and again weighed.

This was the longest time allowed in water, having found in former tests of the same nature that the absorption of water by the brick was practically complete in thirty minutes.

The table of absorption is given below:

Kind of Brick.	Weight Dry.		Weight after 20 Minutes in Water.		Weight after 30 Minutes in Water.		Absorption in Ounces.	Absorption in °/°
	lbs.	ozs.	lbs.	ozs.	lbs.	ozs.	ozs.	
Kingston Road, 1st class..	5	5¾	6	0	6	0	10¼	11 9
“ “ 2nd “	5	5½	6	2¼	6	2¼	12¾	14.9
“ “ 3rd “	5	1¾	6	2¼	6	2¼	14¼	17.1
Carleton Clinker.........	5	0¼	5	10	5	10½	10¼	12.7
“ 1st class .	5	0½	5	13½	5	13¾	13¼	16.4
Yorkville .....1st class..	4	10½	5	11¾	5	11¾	17	22.7
“ .....2nd “	4	11¾	6	0	6	0	20¼	26.7
Humber........1st “	5	7½	6	2½	6	2½	11	12.6
“ ....2nd “	5	8	6	6¾	6	4¾	14¾	16.7
Don Valley Pressed, red..	5	13¾	6	6	6	6½	8¾	9.3
“ “ buff..	5	0	5	15½	5	15¾	15¾	9.7

To ascertain the crushing strength of each quality of brick, two fair and sound samples were selected and bedded between thin layers of Portland cement, thus giving two parallel planes without injury of any kind to the brick.

The following table shows the crushing strength of the different bricks used:

ULTIMATE CRUSHING STRENGTH OF COMMON AND PRESSED BRICK.

Class of Brick.	Height.	Area Exposed to Crushing in Inches.	Ultimate Load in Pounds.	Crushing Strength in lbs. per sq. inch.
Kingston Road, 1st class...	2½	8¾ x 4 35	132400	3783
" 2nd "	2½	9 x 4⅛ 37	62000	1670.
	2½	8⅞ x 4⅛ 36.6	63000	1721
" 3rd "	2⅝	9 x 4⅛ 37	67600	1821
	2⅝	8⅞ x 4⅛ 36.6	68000	1857
Carleton Clinker..........	2½	8⅝ x 3⅞ 33.4	190000	5685
" 1st class...	2½	8¾ x 4 35	112000	3200
Yorkville..... 1st "	2⅝	8⅝ x 4 34.5	160000	4637
" ....2nd "	2½	8¾ x 4 35	107000	3057
	2½	8¾ x 4 35	112000	3200
Humber........1st "	2¼	8⅞ x 4 35.5	43400	1222
	2½	8⅝ x 4 34.5	50000	1449
" ....2nd "	2½	8⅞ x 4¼ 36.6	72000	1966
	2½	8⅞ x 4¼ 36.6	64000	1748
Don Valley........red....	2⅜	8⅜ x 4 34.3	184000	5372
" ....buff		8½ x 4⅛ 35	125000	3571

The piers were built by a skilled bricklayer, who also provided the lime mortar, which consisted of 4½ yards of Bloor street coarse sand to ten barrels of lime, this being about the proportion of two parts sand to one part lime. The cement mortar was mixed in the proportion of three parts sand to one part of good Portland cement. While the piers were being built, two cubes of each class of mortar were prepared and set aside for the purpose of ascertaining their resistance to crushing, thus giving a complete record of all the materials used.

ULTIMATE CRUSHING STRENGTH OF MORTAR 2½ MONTHS OLD.

Class.	Height. Inches.	Area Exposed to Crushing in Inches.	Ultimate Load in Pounds.	Crushing Strength in lbs. per sq. Inch.
Lime mortar—2 to 1.......	5	4⅝ x 4⅞ 22.5	1200	53
Lime mortar—2 to 1.......	4⅞	4⅝ x 4¾ 22	1700	77
Cement mortar—3 to 1	5	5 x 5 25	33800	1352

The piers were built and laid aside to harden in the mechanical laboratory of the School of Practical Science, in a temperature which averaged about 60° Fahrenheit, and were prepared for the test as follows: A thin mortar of neat cement was spread on a smooth cast-iron plate, and the pier placed upon the mortar and left until the cement hardened. The bottom bed was then trimmed off flush with the sides, the pier placed on the testing machine, and a layer of neat Portland cement mortar was placed on top, the pier was slid under the head of machine, and the head was brought to its bearing while the mortar was yet soft.

This method ensured two parallel beds and gave a uniformly distributed stress on the pier. The load was applied slowly and continuously, until complete failure of the pier occurred.

Pier No. 1:

Description....Humber, 1st class, laid in lime mortar ⅜″ joints.
Size of pier, 9″ × 9″..................area, 81 square inches.
Length, 24 courses..........................73 inches.
Age ....10 days.
Ultimate load...........................23,600 pounds.
“ strength per sq. inch..................291 pounds.
“ “ “ foot. ....20.9 tons.

This pier was built on the testing machine; with lime mortar on top and bottom bed, the head of machine was brought down to a level bearing, and pier allowed to harden in position for ten days.

The pier failed by spreading a little at the head, a wide crack running down the centre to about half the height of the pier.

Pier No. 2:

Description....Kingston Road, 1st class, laid in lime mortar with ⅜″ joints.
Size of pier, 8⅞″ × 8⅞″............area, 78.75 square inches.
Length, 8 courses...........................23 inches.
Weight ....114 pounds.
Age ....2½ months.
Ultimate load...........................44,000 pounds.
Crushing strength per square inch...............558 pounds.
“ “ “ foot ....40.2 tons.

The pier sustained a high load without sign of fracture, but was completely destroyed under the ultimate load.

Pier No. 3:

Description....Kingston Road, 2nd class, laid in lime mortar with ⅜″ joints.
Size of pier, 9″ × 9″ ....area, 81 square inches.

Length, 8 courses	24 inches.
Weight	114 pounds.
Age	2½ months.
Ultimate load	22,000 pounds.
Crushing strength per square inch	Not determined by experiment.
“ “ “ foot	

The bottom bed used in this case was the one-inch board upon which the pier was originally built; the board appeared to be slightly warped, and split under the application of the load, causing a variation in the stress, to which is due the early failure of the pier.

Pier No. 4.

Description . . Kingston Road, 3rd class, laid in lime mortar with ⅜″ joints.

Size of pier, 9″ x 9″	area, 81 square inches.
Length, 8 courses	24 inches.
Weight	110 pounds.
Age	2½ months.
Ultimate load	24,000 pounds.
Crushing strength per square inch	296 pounds.
“ “ “ foot	21.3 tons.

Failure occurred by splitting of the bricks in the upper courses, then wide vertical cracks opened throughout the whole length, and under highest load every brick in the pier was shattered.

Pier No. 5:

Description . . Humber, 1st class, laid in lime mortar.

Size of pier, 9″ x 9″	area, 81 square inches.
Length, 8 courses	24 inches.
Weight	122 pounds.
Age	2½ months.
Ultimate load	28,000 pounds.
Crushing strength per square inch	346 pounds.
“ “ “ foot	24.8 tons.

The pier held well together until near the ultimate load, then long continuous cracks appeared, with final rupture of the whole pier.

Pier No. 6:

Description . . Humber, 2nd class, laid in lime mortar.

Size of pier, 8¾″ x 8¾″	area, 76.5 square inches.
Length, 8 courses	23½ inches.
Weight	118 pounds.

Age.................................2½ months days.
Ultimate load.......................22,400 pounds.
Crushing strength per square inch...............293 pounds.
“ “ “ foot...................21 tons.

All the bricks in the upper portion were completely shattered, the principal failure occurring along one corner of pier.

Pier No. 7:

Description . . Carleton Clinker, laid in lime mortar with ⅜″ joints.
Size of pier, 8⅝″ x 8⅜″...............area, 72 square inches.
Length, 8 courses...........................22 inches.
Weight.....................................114 pounds.
Age..2½ months.
Ultimate load..............................44,000 pounds.
Crushing strength per square inch...............609 pounds.
“ “ “ foot.................43.8 tons.

The pier failed, with continuous lines of fracture up and down the four sides, only one brick on the lower bed being uninjured after the test.

Pier No. 8:

Description . . . . Carleton, 1st class, laid in mortar with ⅜″ joints.
Size of pier, 8¾″ x 8¾″.............area, 76.5 square inches.
Length, 8 courses...........................23½ inches.
Weight.....................................110 pounds.
Age..2½ months.
Ultimate load..............................41,000 pounds.
Crushing strength per square inch...............535 pounds.
“ “ “ foot.................38.5 tons.

The pier was completely shattered under the highest load. The mortar crumbled out like sand, and had very little effect in holding any portions of the pier together.

Pier No. 9:

Description . . Yorkville, No. 1, white brick, laid in lime mortar with ⅜″ joints.
Size of pier, 8¾″ x 8¾″.............area, 76.5 square inches.
Length, 5 courses...........................14½ inches.
Weight.....................................65 pounds.
Age..2½ months.
Ultimate load..............................39,000 pounds.
Crushing strength per square inch...............509 pounds.
“ “ “ foot.................36.6 tons.

Small cracks appeared as the load was put on. As the highest load was approached portions of the side of the pier spalled off, and finally shattered to fragments under the highest load.

Pier No. 10:

Description..Yorkville white brick No. 2, with pinkish shade, laid in lime mortar with ⅜″ joints.
Size of pier, 8¾″ x 8¾″..............area, 76.5 square inches.
Length, 8 courses..........................23½ inches.
Weight...105 pounds.
Age..................................2½ months days.
Ultimate load..................................30,000 pounds.
Crushing strength per square inch..............392 pounds.
" " " foot.................28.2 tons.

Fine cracks appeared early in the test, which increased to long vertical cracks, running the length of the pier, portions of the brick spalled off, and under the highest load given above the pier was totally destroyed.

Pier No. 11:

Description..Don Valley pressed brick, buff color, laid in lime mortar.
Size of pier, 8⅝″ × 8⅝″.............area, 74.4 square inches.
Length, 8 courses.................................21 inches.
Weight..97 pounds.
Age...2½ months.
Ultimate load..................................51,000 pounds.
Crushing strength per square inch...............686 pounds.
" " " foot.................49.4 tons.

As the highest load was approached, fine cracks appeared, which were confined to individual bricks, and were not continuous down the length of the pier; the fracture was rather of a crumbling nature.

Pier No. 12:

Description..Don Valley pressed brick, red color, laid in lime mortar.
Size of pier, 8½″ × 8½″............area, 72.25 square inches.
Length, 8 courses................................21½ inches.
Weight...110 pounds.
Age...2½ months.
Ultimate load..................................88,000 pounds.
Crushing strength per square inch..............1,218 pounds.
" " " foot.................87.7 tons.

The failure of this pier was of somewhat the same nature as that of the last, but the brickwork held together better under the ultimate load.

CEMENT PIERS.

Pier No. 13:

Description . . Yorkville, 1st class, white color, laid in cement mortar.
Size of pier, 8⅝″ × 8⅝″ . . . . area, 74.4 square inches.
Length, 8 courses . . . . 24 inches.
Weight . . . . 110 pounds.
Age . . . . 2½ months.
Ultimate load . . . . 79,000 pounds.
" " per square inch . . . . 1,062 pounds.
" " " foot . . . . 76.5 tons.

The pier held together well, and did not show much sign of failure until the highest load was reached; the pier was destroyed in the test, probably owing to the brittle nature of this brick.

Pier No. 14:

Description . . Yorkville, 2nd class, color white with pink tint, laid in cement mortar.
Size of pier, 8¾ × 8¾ . . . . area, 76.5 square inches.
Length, 8 courses . . . . 24 inches.
Weight . . . . 111 pounds.
Age . . . . 2½ months.
Ultimate load . . . . 78,000 pounds.
" strength per square inch . . . . 1,018 pounds.
" " " foot . . . . 73.3 tons.

This pier was well built, and shows the value of a cement mortar for laying brickwork, as its binding qualities allows the brick to develop nearly its full strength.

Pier No. 15.

Description . . . . Humber, 2nd class, laid in cement mortar.
Size of pier, 9″ × 9″ . . . . area, 81 square inches.
Length, 8 courses . . . . 24 inches.
Weight . . . . 124 pounds.
Age . . . . 2½ months.
Ultimate load . . . . 91,600 pounds.
" strength per square inch . . . . 1,131 "
" " " foot . . . . 81.4 tons.

Fine cracks occurred in some of the bricks only under nearly the highest load, but total destruction of the pier took place under the ultimate load, but did not shatter so badly as in the case of those laid in lime mortar.

Pier No. 16 :

Description	Kingston Road, 2nd class, laid in cement mortar.
Size of pier, 9″ + 9″	area, 81 square inches.
Length, 8 courses	23½ "
Age	2½ months.
Ultimate load	69,000 pounds.
" strength per square inch	852 "
" " " foot	61.3 tons.

This pier held together even under the ultimate load, the failure occurring through actual crushing of some of the upper bricks. After pier was removed from the machine, only small portions of it could be forced away from the mass.

Pier No 17 :

Description	Carleton Clinker, laid in cement mortar.
Size of pier, 8½ × 8½	area, 72.25 square inches.
Length, 8 courses	22¾ inches.
Weight	115 pounds.
Age	2½ months.
Ultimate load	174,000 pounds
" strength per square inch	2408 "
" " " foot	173.4 tons.

Fine cracks appeared toward the end of test ; these cracks were not continuous down the length of pier, nor did they increase much in width under the highest load.

Pier No. 18 :

While working on this pier the friction clutch of the machine gave way, and the tests were discontinued for the present.

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PREFACE

The proceedings of the Engineering Society of the School of Practical Science for the academic year 1896-97 are herewith respectfully submitted.

The Society congratulates itself on having received such valuable contributions for the present issue, and extends its thanks to those who have taken such an interest in its welfare.

The progress of the previous eleven years has been enjoyed during the year which is just closing.

Papers in all the branches of engineering and architecture are respectfully solicited.

The demand for the publication steadily increases.

The present issue consists of fifteen hundred copies.

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ENGINEERING SOCIETY

—OF—

The School of Practical Science

TORONTO.

THE PRESIDENT'S ADDRESS.

GENTLEMEN,—As President of the Engineering Society it affords me great pleasure in welcoming you to this, the opening meeting of another academic year, and to wish you every success through it.

To those who are about to enroll themselves in our Society, I extend a hearty welcome, and assure them that the time spent with us, in pursuit after knowledge, will be most profitably spent.

The past summer has impressed upon me, very forcibly, my great inability to fill the office of President as it should be filled, and as it has been filled by those who have held the position before me. It is the highest honor it is the privilege of an undergraduate to receive, and any expression of thanks that I could make would but feebly express my sincere appreciation of the honor thus conferred upon me.

While deeply impressed by my own inability, I hope, with the assistance of the able committee you have elected to counsel me, to place the Society still higher in the engineering world than it is at present, which, gentlemen, is hoping a great deal indeed.

I am sorry that two of our most energetic members have found it necessary to tender their resignations as officers of our Society. I refer to H. L. Vercoe, corresponding secretary, and J. A. De Cew, fourth year representative. It is pleasant to know, however, that they have obtained responsible positions, which they will, no doubt, fill with credit to themselves and to their Alma Mater.

We have great reason to be proud of the position the Society now holds. Many are the requests received from eminent engineers and men of business, and also from institutions of world-wide importance, for copies of our pamphlet. The demand for last year's pamphlet was indeed gratifying, and should be no small amount of gratification and reward to those who contributed to its success.

Owing to the untiring efforts of the past President, Mr. G. M. Campbell, and his colleagues, the financial position of the Society is beyond our wildest hopes. Their work, together with that of our present treasurer, Mr. Piper, has placed us in a financial position which we have seldom enjoyed at this time of the year.

It is proper, I think, on this occasion to take a rough glance at the aims and objects of the Society, for the benefit, chiefly, of those who are with us for the first time.

The officers consist of a president, vice-president, corresponding secretary, recording secretary, treasurer, librarian, graduate representative, and representatives from the fourth, third, second, and first years.

Our meetings are held every second Wednesday of the academic year, when papers are read by members and others on subjects of interest to us in our chosen professions.

It is well to mention that these meetings are virtually part of the regular course of the school. Drafting rooms are closed, and no lectures are given, and every student is expected to further his own interests, and those of the Society, by regular attendance at these meetings.

The objects of the Society, according to Constitution, are: (1) The encouragement of original research in the science of engineering. (2) The preservation of the results of such research. (3) The dissemination of these results among its members. (4) The cultivation of mutual assistance among the members in the practice of engineering.

In our library are many books on subjects of greatest interest to our members, and no student should let the opportunity thus afforded pass unaccepted. During the summer vast improvements have been made in the library, which will tend to give greater satisfaction to all parties desiring to borrow books.

The books are now all locked up, and access to them can only be had by two parties, viz., the Librarian and one of the Fellows of the School, whom the faculty have decided to appoint as Assistant Librarian, and whose duty it will be to look after the books lent to the faculty and to the fourth year.

Much dissatisfaction has been expressed to me of the mode followed in the lending of books, and I would earnestly propose the appointment of a committee to revise the library rules, so that it may be run on a more systematic basis.

As most of you are aware the Librarian is ready to supply drafting paper at cost price.

As regards the Constitution: It is very important in the interest of the Society that the Constitution should not only be up to date, but in such a shape as to be readily accessible to all interested in it.

In looking at the Constitution of the Society as it now stands, I find that a number of clauses have been added to those printed in 1893, with which few are familiar, also that a number of others are conflicting and misleading. I consider that the Constitution as it is to date is too bulky altogether, and that a number of laws are there which are not being followed out. For instance: A by-law now exists calling for the publication of advance sheets of the papers read before the Society, which are to be distributed to outside members soliciting discussions. Now this law has been found by experience to be too costly an undertaking by the Society, and has been discarded by the committee as impracticable. Yet, being a law of the Society it should be followed out. It has been proved beyond a doubt that we are unable to follow this law at present at least, and therefore it should be struck out.

Another case: A whole article is in our minute book, and is part of our laws, but is not published, and thus many of us are groping wildly in the dark as regards the substance of our Constitution.

I would advise a committee of five to be appointed to revise the Constitution, and report to us at the next meeting of the Society, which shall take the form of a constitutional meeting. It is of the utmost importance to us as a Society that this be done without delay, so that a published Constitution can be placed in the hands of the members as early as possible, in order that every student may be acquainted with our laws. I would advise that this committee make as few laws as possible, and to make them plain and forcible.

As most of you are aware, the Council of the School have come to the assistance of your committee in the matter of obtaining papers from the undergraduates.

Every paper read by an undergrad. is examined and marked according to merit, 100 marks being the maximum; all marks over 50 are to be considered in granting honors at the annual examinations. This in itself is a great inducement, but others of greater importance are evident.

The writing and reading of a paper before the Society is beneficial to every one. It imparts your knowledge of the subject in hand to those who are less favored in that line and solicits discussion from those who are in a position to criticize. Besides this it gives one confidence in public, and fits him to be conversant in all lines of his profession when cast adrift from his friends on the vast world, where at any time he may be called to defend his principles and assert his convictions.

I earnestly invite discussion on the papers read, as do also the writers. If anything is said that you do not understand, ask about it; and if anything is said that you do not believe, question it, as it is by this means, greatly, that knowledge is imparted. Do not let the fact of your being in the first year hinder your freedom of speech, as here in our meeting no year distinction exists as regards debate.

I most earnestly solicit papers from the undergraduate members, and hope that the inducements offered to them will be seriously considered.

While we, as a society, have been making great progress, as a student body we have been equally successful on the platform and in the field.

Last year we entered into a debate with the Literary Society of the University and came away more than conquerors. This year I hope we shall be ready to meet and vanquish the best men the University can send to oppose us.

In the field we again swept everything before us, and through "feats of strength" and "fleetness of foot" have succeeded in fulfilling the wish of all. "We have made the name of the S.P.S. both feared and respected in the College and on the Campus."

It behooves us, gentlemen, to keep the enviable position we now hold, and every one should make it his individual duty to see that we do so.

It is with deep regret that I have to record the painful accident which has befallen one of our members, Lockie Burwash. In his endeavor to keep the name of his Alma Mater before the eyes of the public he received a hurt which will confine him to his bed for a time. On behalf of the Society I wish him a speedy recovery, and hope that ere long he may be amongst us again.

I extend the congratulation of the Society to those who have been reappointed on the staff of the School, and on its behalf promise them a loyal support.

And now, gentlemen, I will simply add that the results of the past are before you, those of the future are ours to make. May they be such as will reflect the highest credit on our preceptors, and on the School of Practical Science of our loved Province of Ontario.

C. FRANK KING.

NOTES ON THE STAMP MILL.

By J. W. Bain, Grad. S. P. S.

The year 1849 was a memorable one on the Pacific coast of North America; the discovery of auriferous sands of great richness attracted thousands to the wilds of California, and mining camps sprang into existence all over the country. Gradually the placers became exhausted, and when similar deposits were discovered on the Columbia in 1858, many Californians started off to try their luck in the new El Dorado.

It occurred to some Californian miners that what had been done by natural agency might also be accomplished by man, and the outcome of the idea was the application of the stamp mill to crushing gold quartz. Although successful on rich ores, the first mills were extremely crude and wasteful; but experience and careful study of their defects have brought the process to its present efficiency.

It is not the purpose of the writer to trace the evolution of the stamp mill, which would be, truly, a somewhat laborious task, but rather to describe very briefly some features of modern mills and milling.

The series of operations for the extraction of gold in most modern stamp mills may be briefly stated as follows: The ore from the mine is crushed roughly, and fed automatically to the mortar of the stamp battery; this is provided with amalgamated copper plates, which catch most of the free gold. The rest being carried by water escapes through a screen with the finely divided ore, where more of the free gold is caught on other amalgamated plates. From these plates the ore passes to concentrators, which separate most of the remaining gold and nearly all of the sulphides from the gangue. This last usually still contains some small quantity of gold, which may be extracted chemically, or allowed to run to waste.

In order that some idea of the equipments of a mill may be obtained, a few brief notes upon some of the more important machines are given:

Crusher.—The Blake, Dodge, Gates or Comet, are in general use. These are described fully in most works on the metallurgy of gold, so that little need be said about them. In the Blake machine the crushing is done by that part of the jaw most remote from the supporting axle; in the Dodge this arrangement is reversed. Evidently the variation in breadth of the jaw opening of the Blake will be much greater than in the other case, and the product will be more variable in size. It must not be forgotten, as an offset, that the Dodge has not as large a capacity, and hence the matter becomes to some extent a question of preference. General practice seems to favor the Blake.

For handling large quantities in separate crusher houses, the Gates or Comet appear to be the best machines. They run very steadily, and have little jar; the capacity is larger, but on the other hand they are more complicated and very heavy.

Whatever form of crusher be used, the jaw opening should be as small as possible, because it has been found that the cost of reduction by these machines is only one-fifth of what it is by stamps. Wherever possible, the rock breaker is placed in a separate building; this is done for two reasons. In the first place, if situated high up in a mill, the reciprocating motion of the heavy jaw causes much vibration, which is most noticeable when the stamps are hung up; but it is also felt when they are in motion, as there is considerable jarring while large pieces of ore are being fed. Secondly, much fine dust is produced, and this readily finds its way into the bearings of the machines located on a lower story, with prejudicial results. In many cases, however, circumstances will not permit of this arrangement, and the crusher is placed above the ore bin.

If possible, power should be supplied from a separate motor, since the action is irregular, and tends to disturb the running of the stamps and concentrators when connected with them. The suggestion that this motor be applied at night to driving a dynamo seems to be a good one.

In many mills, a grizzly is used; this is simply an inclined grating made of long iron bars, or light rails, laid side by side, and spaced the same distance apart as the jaw-opening of the rock-breaker. The ore is dumped over it; what passes through falls into the ore bin, while the rest is fed to the crusher.

Ore Bins.—These should be as large as convenient, holding at least twenty-four hours' supply. If an accident happens to the hoist, or the mine is flooded, the mill would have to be stopped if no supply were kept; and it has been found that intermittent working is the more costly. In some American mines as much as a fortnight's supply is always kept on hand.

Feeders.—The early mills were fed by hand, a practice entirely obsolete at present. The machine feeder is able to handle at least fifteen per cent. more per hour, according to a recent estimate, and this alone warrants its adoption. At present, feeders of the Challenge or Tulloch types are the most widely used. The principle upon which they are designed is this: when the layer of ore on the dies becomes thin, the stamp falls farther and strikes a bumper rod; the latter actuates a system of levers, and some ore is delivered from a hanging or revolving tray. The depth of the layer of ore in the mortar is thus automatically regulated by a simple attachment on the feeder. The Tulloch, which is the cheaper and commoner of the two, has a suspended tray; when damp ore is being fed, a hard cake usually forms on it, necessitating frequent inspection; in other respects it is a good feeder and is easily regulated. The Challenge employs a revolving plate provided with scrapers, so that it works equally well on all ores; it is slightly more complicated in construction, but is generally regarded as the better machine.

The feeders are mounted on light wooden frames, which run on rails, and are so placed that the ore shoots are directly over the hoppers. In some of the most recent machines, the hopper is done away with and the feeding mechanism attached to the shoot; a little room is gained by this arrangement.

Battery.—The early Californian mill had stamps weighing from 500 to 600 pounds, making 16 to 18 inch drops at the rate of 20 to 25 per minute. Contrast this with modern practice, which employs stamps weighing 850 to 1,000 pounds, making 6 to 8 inch drops at a rate of 80 to 105 per minute. This is perhaps the most radical of the many changes which have been made, but there is no doubt that it is a step forward. To day we crush from 1½ to 4½ tons per 24 hours, as compared with 1 ton twenty-five years ago, and the cost per ton is considerably reduced at the same time.

The modern mortar is of iron entirely; the shoes and dies of cast iron or cast steel, as may be most economical; the screens of Russia iron, tinned plate, brass wire, or phosphor-bronze; and the battery frame of wood, iron or steel. From this enumeration it can be easily seen that anything of the nature of a discussion on these parts would be much too lengthy. We may notice that the introduction of steel frames is of importance to South Africa and Western Australia, although wood is still largely used. The employment of phosphor-bronze screens will perhaps help the millman; hitherto rust has eaten the Russia or tinned iron and potassium cyanide has clogged the brass. Cast steel cams are in almost universal use, and much trouble and delay is spared.

Deep mercury wells are employed to prevent loss, but they are simple affairs and need no comment.

The plates are now silver plated, and are carefully tended by experienced men. In some mills the apron plate is stepped; that is, two short plates are used, one being placed two inches above the other, so that there is a slight fall. This is done because it has been noticed that the largest deposit of gold occurs at that point where the pulp from the mortar strikes the plate; the stepping saves a higher percentage of gold, but is a trifle inconvenient. As many as six steps are used in some places.

The practice of sizing the pulp before it goes to the concentrators has been adopted in many places. The most common sizer is Rittinger's pointed box, either in its original form, or a slight modification. The apparatus is simple, and can be constructed by an ordinary carpenter, so that the experiment can easily be made. A large box, if well designed, will handle very satisfactorily a considerable volume of pulp, and increase the efficiency of the concentrators appreciably.

CONCENTRATING APPARATUS.—The belt vanner is, of course, the favorite, although in Colorado and Australia the shaking table is much used. Concentrating apparatus has been a favorite field for the inventor, and a number of mills have adopted some special machine. In the main, however, the two mentioned above rank easily first. Speaking generally, the vanner is perhaps the best machine for general work, and makes a good showing on either sized or unsized pulp. The shaking table is not so efficient in rough work; on sized pulp it gives good, clean concentrates, but can not handle slimes as well as its rival. The common practice is to use two vanners, or one shaking table to every five stamps. The corrugated instead of the plain belt in machines of the Frue type is a recent improvement, which is yet apparently in the experimental stage.

The cleanness of the concentrates will be purposely varied in different mills. In an establishment where they are sent to a distant smelter the purity becomes important; if, on the other hand, there is some plant for their treatment on the premises, the more perfect separation from the gangue is aimed at.

In some localities in California the Cornish or German methods of ore-dressing are used. The pulp is treated on buddles or in tossing tubs, and the slimes in jigs. The practice is local, and is applied to high grade ores. The saving in most ores would probably not repay the outlay on plant.

Blankets or canvas tables are sometimes used instead of concentrators, or as an adjunct to them. The method is simple, and consists in running the pulp over either of the above materials; the heavier particles, being at the bottom, are caught on the rough surface, from which they are removed by washing. Canvas plants are in use in California and Colorado, and do good service with slimes, retaining nearly all the fine gold, floured mercury and amalgam.

Tailings are usually allowed to go to waste, but in South Africa they are in many cases treated by the cyanide process, and yield handsome returns. Where water is scarce they are run into reservoirs, and allowed to settle; the supernatant liquid is pumped off and used again. And here it may be noticed that very often the tailings from a mill carry a considerable amount of gold. This arises from the fact that the cost of extraction would probably be more than the value saved. The older mills lost a quantity of gold in this way, but not for the same reason. The mill man then was simply a miner or laborer, with a smattering of mechanical knowledge, who kept the machine running, and paid little attention to the plates, if, indeed, he understood anything about them. Such slipshod methods worked their own retribution, and the selection of a mill man is now an important matter.

Concentrates may be worked in three ways:

(*a*) AMALGAMATION.—This process is being rapidly superseded by others. It consists in grinding the material in a pan with mercury for some hours; the constant attrition and agitation favor the amalgamation of the gold.

(*b*) CHEMICAL METHODS.—1. Chlorination.—Concentrates have been worked very satisfactorily and cheaply in many places by this process, but there has been signal failure in others. 2. Cyanidation.—This is the most modern, and perhaps the best of these methods. Especially in South Africa has it been successful, and like instances elsewhere are not wanting. The precipitation of the gold from solution is perhaps the weakest point in the process, and the efforts of inventors have been directed towards the improvement of the operation.

(*c*) SMELTING.—The concentrates are added to the charge of a lead, or copper smelting plant, and base bullion is produced. In the former case, the gold is separated from the lead by Parke's process; in the latter, the precious metal may be conveniently obtained by electrolysis. This is done by running the coarse metal into slabs, and then depositing the copper electrolytically on pure sheet copper, the precious metals separating as mud in the bottom of the vat.

The cost of treatment in some representative mills in the districts mentioned below, is seen in the following table.

DISTRICT.	PROCESS.	COST.	Tons treated per 24 hours.
California	Chlorination	$13 40	3.5
South Carolina	"	4 62	.4
Alaska	"	8 99	12.75
South Africa	Cyanidation	92	....

These figures represent the cost under certain conditions, and must not be taken as general estimates.

A good deal has been written lately about the efficiency of the stamp mill. Some maintain that, as a crushing machine, it is remarkably inefficient, while it is claimed by others that although it has defects of no small magnitude, that nevertheless the efficiency is high. Certain it is that other machines, for which much has been prophesied from a theoretical point of view, have failed signally in competition with stamps. A notable instance is the Huntington mill; a good machine for soft ores, and used with great success at the Spanish Mine, California, where the cost of milling per ton is only twenty-five cents. One of the main reasons for the non-success of the Huntington mill, in many places, is that it is complicated, and requires careful watching, involving extra expense for labor. Such apparently trifling considerations carry much weight in many instances, and the best machines for a mill are not always those which are most efficient in other localities.

An improvement on the old mills is worthy of notice, viz., the automatic handling of the ore. The aim of the designer is to obviate the necessity of employing any extra labor. The reason is apparent; labor may cost two dollars per day, and in milling a low grade ore any additional expense is bound to affect the returns more or less. This calls forth the remark that the successful treatment of a low grade ore demands the most systematic handling that can be devised.

Another tendency is perceptible of late years, that directed towards improvement in concentrating. This involves the study of the various machines used in the concentration of other ores, and the result of these experiments has led to the adoption of some of the simpler apparatus, such as Rittinger's pointed box. The extent to which dressing operations should be carried is at present problematical; it is not unlikely that the nature and richness of the ore, together with the variation in the cost of operating the plant, will militate against the adoption of any common system. The importance of sizing before concentrating is being generally recognized, but the installation of a more or less complete system seems to be a rather hazardous experiment from a financial point of view. This question is a very interesting one, and would require a thorough examination of some mining district before it could be handled satisfactorily with regard to that region.

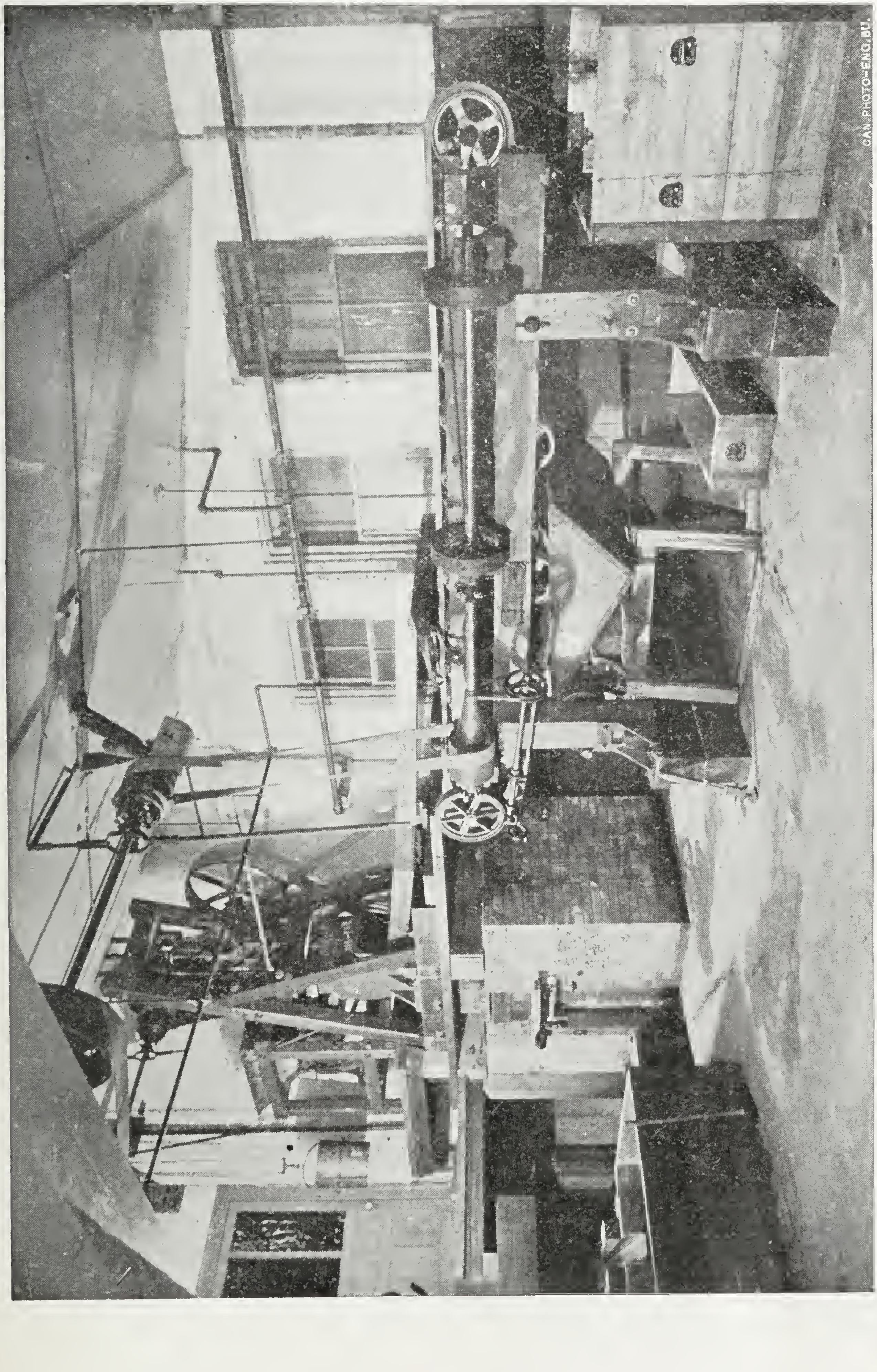
As to the cost of milling little can be said. Local conditions are the chief factors, and no one sum can be given as an average value. Water power is much cheaper than steam; the cost of the latter varies with the price of fuel, and wages differ everywhere.

The figures opposite each district in the following table represent the cost at some mill in that locality. These establishments have been chosen as representative by a good authority:

DISTRICT.	Number of Stamps Running.	Weight of Stamp.	Tons Treated per 24 hours.	Cost of Milling per Ton.
Grass Valley, Cal.	40	850	1.6	81c.
Alaska	240	900	2.9	44
Nova Scotia	10	...	2.9	35
Bendigo, Victoria	40	900	2.3	58
Gilpin Co., Col.	75	550	1.0	75

In the west of our own province the cost of milling is said to be high, but statistics are wanting, and nothing definite can be given. The district is new, and the operations carried on up to the present are, in a certain sense, experimental. Some of the results are exceedingly promising, and there is apparently nothing to prevent the establishment of a flourishing industry in gold winning.

In presenting this series of notes, the writer regrets the fragmentary nature of the whole; but as has been said before, the salient features alone have been touched on. For details, reference may be made to the following works: "Metallurgy of Gold," by Manuel Eissler; and "Gold," by T. K. Rose.



Stamp Mill used in Laboratory, School of Practical Science.

ROADS AND STREETS IN ONTARIO.

By A. W. Campbell, C.E., Provincial Road Commissioner.

The study of road construction in Ontario must necessarily be very largely of a theoretical nature since we have, as yet, little or no local practice to guide us. For this reason, I purpose, in a brief paper, to merely touch upon a few of the prominent points which enter into the building of a roadway, with a view to more clearly define the situation as we find it in the settled districts of this province to-day.

The civil engineer when undertaking the construction of a road in Ontario, must first of all free himself of the idea that European practice, in all details, can be transferred to Canada without alteration. Ontario has a climate very different from that of England or France, or even of some of the Eastern States in America, to which we are beginning to look for information. Ontario is subject to extremes of heat and cold such as are not experienced in England. The English climate is largely one of continuous drizzle. In Ontario we have seasons of drought followed by torrential rains, but this drought is not so long continued as we frequently find it in some of the Eastern States. England is much more densely populated than Ontario; there is greater wealth in proportion to the road mileage, and the demands of traffic and travel are different. At the same time, all experience teaches something, and in its judicious application lies the skill of the engineer. One of the most important lessons we learn is that the methods of one country are rarely applicable in all their details to the requirements of another.

The actual construction of a road is a matter of an exceedingly local nature. Just as the methods of one country cannot be transferred, in all details, to another, so we find that the plans best adapted to one township or county, may have to be modified when transferred to an adjoining municipality, in order to fit the road to altered local conditions and requirements. Not only must the civil engineer understand how to build a good road when he has a given climate, and a given quality and class of material, but he must remember that there is an economic fitness which must be produced, otherwise the road is a failure. There is this commercial aspect which the successful engineer always zealously regards, and which must always affect our plans, however correct from a designer's standpoint. For these reasons, one cannot condemn utterly any class of pavement. Cedar block pavement is popularly supposed to be a failure, but it is not difficult to conceive of conditions under which it would be the most suitable that could possibly be employed. An asphalt roadway has its uses, so a vitrified brick pavement, a crushed stone, or gravel, and in very many cases, from an economic standpoint, a dirt driveway is the best adapted to all circumstances.

The problem of paving and roadmaking is largely one of good drainage. I do not mean to say that the quality of the road covering is unimportant, nor the crowning, nor any of the other details, but I do mean that the object is largely drainage. We first make a proper use of underdrains to secure a firm foundation ; then we round up the natural earth into such a shape as to shed the water readily to the side gutters ; then over this we place a covering such as will prevent water penetrating to the earth sub-soil, and of a quality that the traffic which it must accommodate will not destroy, preventing the water passing to the gutters. The problem is very simple in the abstract. In the actual solution, there occasionally arise differences of opinion. No paving material as now used, whether asphalt, brick or crushed stone, is sufficient to bridge over a wet and yielding sub-soil, and this is more especially the case in Ontario because of the upheaving action of frost. It is important to remember that a dry natural sub-soil supports not only the weight of traffic, but the surface covering as well. It was the neglect of this principle which caused the Romans in the days of the Empire to undertake the clumsy construction of roads with artificial foundations of stone and concrete, two and three feet in thickness, a waste of energy which the nineteenth century cannot afford.

As a general thing you will find the country road already located. Unless it is an old trespass road, that is, one of the early colonization roads, it will probably follow the arbitrary lines of our system of surveys, which, as you are aware, places the road allowance in a certain fixed position, according to the width of the concessions and lots. As the cost of building and maintaining a road depends very largely upon the topography of the country and the nature of the sub-soil upon which it is laid, it will be apparent that before undertaking the construction, it is well to consider whether any change of location is desirable. This will involve a study of the geological character of the vicinity. When the paved way can be laid on a base which is loose and porous, the drainage problem will be very much simplified. If the sub-soil is of a retentive nature, a yielding sand, a muck, or a plastic clay, the expense of drainage will be very much increased. Steep grades should be avoided since, at their best, they materially interfere with traffic, and when they necessitate cuts, the objection to them is very much increased. Under the municipal code, the location of roads can be altered, and the engineer must be able to draw almost instinctively upon his training in geology and mathematics, in order to judiciously exercise this privilege.

The metal to be used in forming the surface is an important part of the question. The choice will usually lie between an inferior quality near at hand, and a better stone from a distance. The best material which has yet come to my notice is an exceedingly tough and durable trap rock. This, however, is to be had only at rare intervals in Ontario. A variety occurs in dykes near Kingston, but the city of Cleveland is bringing this rock from Poole Island, near the north shore of Lake Superior, in Canadian waters. North and north-west of Lake Superior it is to be found in areas, millions of acres in extent. The cost of its transportation, however, is an effectual barrier to its use as yet, and the people of this province are not sufficiently educated in street construction to favor its adoption. In works on road construction you will sometimes find the rocks named in order of merit. This, however, is a very unsafe guide. There are varying qualities of the same kind of stone, just as there are varying qualities of the same species of pine. Granites are usually looked upon as excellent road metal, but any that I have yet seen in use in Ontario have not proven satisfactory. Gneiss, of which there is a vast quantity in northern districts, is of varying quality. Limestone is the most common rock in the settled parts of the province. Some varieties rank very high in wearing qualities, but as a general thing it is not the most durable stone. What this rock lacks in wearing qualities is largely offset by its splendid cementing properties. Field boulders are very plentiful in many localities, and while not sufficiently homogeneous in quality, nor of such a shape as to consolidate with the minimum of vacuum, and are apt to have been affected by the atmosphere, yet they make a good road metal if care is taken to discard those of an inferior variety or which show signs of decomposition. Gravel is another material commonly used. That taken from pits and of glacial origin is generally found to contain too much sand, and large boulders. By screening and crushing, however, serviceable metal will result. That in the eastern part of the province is a blue gravel, composed largely of trappean rock, while in the western district a limestone or "cement" gravel predominates. In estimating the value of any road metal, the only satisfactory test is actual wear on the road, a test which cannot be duplicated in the laboratory. Of course experiments performed in the laboratory, tests of absorption, abrasion, impact, crushing strength, etc., are by no means to be overlooked; but unless the results of these are very pronounced, a stone cannot be readily condemned in the absence of actual experience.

Street improvement in towns is in a state of transition. Places which have not quite reached the status of cities, have not yet discarded their old methods and systems which have obtained since the appearance of the first settlers, perhaps a century ago; but this condition of affairs is fortunately beginning to show signs of a change. Ordinarily we find town councils appropriating a few thousand dollars annually for street work. This is spent, usually, in endeavoring to keep dirt roads in a passable condition, in depositing a few inches of gravel annually on some of the leading streets, in patching plank sidewalks, and in making repairs to structures which have never been built. The council's chief adviser, foreman and street force frequently consist of one man, whose implements comprise a shovel and a wheelbarrow.

In a few years there is going to be a new system of administration over this important department of public work. Progressive towns all over the province are awaking to the fact that they are accomplishing little, except a waste of public money, and a continuation of bad streets. They are coming to the conclusion that expert advice is needed in designing streets, as in many other matters. The difficulty has been, very largely, that people have not known what a well constructed street meant. Not knowing how much there was to learn, they supposed they knew it all, that any man who could shovel gravel was an authority. The time is not far distant when the demand for the services of men competent to oversee street improvement will be considerable.

There is a common impression that, in such matters, it will be sufficient for the engineer to know how to build a road, how to prepare specifications, and how to lay out work for the contractor. By far the most important duty of the engineer, however, is to be able to say what class of improvement should be placed on a certain street, in view of the traffic over, and character of the street; whether asphalt, brick, macadam or some other material which perhaps local circumstances will suggest. Not only must he be able to satisfy himself as to the proper plans to be followed, but he must be able to convince the council, committee, or other body, of which he is the adviser, that he is right; and to do so he must be able to give his reasons in a way that will be understood by a man, perhaps a very stupid man, who has no knowledge whatever of engineering. One of the first steps to be taken in a well regulated administration, would be the preparation of a plan of the town, indicating the class of pavement required on each street, and establishing the grades to be followed when the improvement of any street is undertaken, whether in laying a permanent sidewalk, boulevarding, or in paving the driveway.

Not very many years ago there was little municipal business in this country for the engineer, outside the large cities. Surveying, the retracing of farm boundaries and the division of estates was about the only work for the engineer whose practice was purely local. In 1883 the Municipal Drainage Act was so constructed as to give councils the power, upon petition of the property owners interested, to lay down a scheme for drainage of a certain class, the object being to unite the forces, raise money cheaply, concentrate expenditure by letting contracts, thus accomplishing extensive works which, by the efforts of the individual landowner, could not be affected. In this Act it was specified that the survey should be made, plans prepared, and work reported upon to the municipal council, by an engineer. Strenuous opposition was at once offered by the farming community, which contended that the spirit of the Act was to create work for the engineering profession. In order to remove such opposition, the legislature found it necessary to provide that the word "engineer" may mean any person whom the council might deem competent to perform such services. Generally, in introducing the Act into the municipality, a layman was named as engineer. He staked out the work, but to take levels and determine the grade was beyond his ability, and the report usually specified the depth as three or four feet from the surface of the ground. This resulted in irregular grades, rapid flows and stagnant pools. It required but one experiment to convince the municipal councils that an expert was neceſsary to properly survey and superintend the work. To-day this class of work forms the largest portion of the business of the local engineer, especially in the western portion of the province. The same feeling exists towards road improvement as towards drainage, but in a very short time experience will demonstrate the wisdom and economy of placing public highways, both in urban and rural districts, under the care of skilled road-makers, and the field of the Canadian engineer will be very greatly enlarged, to the benefit of employer and employee. In the older countries, all public works are controlled by departments under the supervision of engineers, and Ontario must sooner or later follow their example. The improvement of roads is one of the most important questions which this country has to face. Very little attention has been given to it in the past by municipal authorities, and very little study has been made of it by engineers. I consider it one of the most important qualifications of the municipal engineer, that he possess a thorough education in this branch of his profession. The country is in need of such men, and is waiting for them.

In concluding this paper, which is necessarily a very superficial treatment of a subject upon which a library might be written, the intention of the writer will be achieved, if some members of your Society will be encouraged to closely observe during the approaching vacation, the most commonplace of our Ontario roads and streets, to notice their defects, and the best means to remedy them ; further to reflect that the municipal engineer, in dealing with this branch alone, street improvement, must combine in the highest degree possible, the qualities of the student, and the diplomat.

SPECIFICATIONS FOR CEMENT CONCRETE SIDEWALKS, WITH SUGGESTIONS.

By A. J. McPherson, B.A. Sc.

Specifications in any case are simply a set of rules and regulations to which the parties to any agreement shall adhere, and by which they shall be governed in any relations they may have with one another, as far as the contract in question is concerned, and as such should be so explicit as to leave no room for doubt as to what they mean on any question to which they refer.

They should also cover the procedure that is to take place under any conditions that are likely to occur. Specifications should not be so severe as to cause any difficulty in having them carried out, and it should be insisted that they be carried out as fully as possible in every particular, for if they are departed from in any one case, one or other of the parties agreeing thereto may confidently expect that they may be construed rather loosely when they may affect him in some other way, and an engineer in thus departing from them would only be making future trouble for himself. Where there are sureties to the contract, also, unless the specifications are carried out in every particular, it may be difficult to hold them, when necessary, to their bond.

It will be noticed that the accompanying copy of specifications is in the form of a blank, including "Instructions to Bidders," and a "Form of Proposal," thus setting forth very plainly the procedure through which the town wishes any contractor to go, and putting all bids that may be sent in on the same basis, so that no injustice is likely to be done in awarding the contract.

The first thirteen and the twenty-sixth clauses may be termed specific, as they refer to the work in question alone, and are simply descriptions of the methods of constructing the works, and are purely engineering in their nature. The remaining clauses are general, and define the relations of the contractors and town authorities in a business way, and might be applied to any contract between the parties aforesaid. These latter clauses might be multiplied a good deal to suit fancied difficulties and conditions that may come up, but we have found that they cover nearly all the essential points, and that it is very seldom that any ambiguity occurs.

When the conditions are very complicated, and when it would be almost impossible to foresee them all, it is a good idea to specify that the interpretation of the engineer, who, most likely, wrote the specifications, and who therefore ought to know better than any others what is meant, shall be taken, and anything not covered by the specifications should be subject to the decision of the engineer or other person in authority during the construction of the works. Sometimes a good deal of trouble is caused by the contractor bringing in a bill of extras at the end of the time, and on long contracts it is very difficult to tell anything about such a bill. It is well to have the clauses relating to extra work well defined and reading in such a way that the cost of any such work would be settled before or at once after it is performed. A good specification in such cases is to require the bills to be rendered at the next payment or within a certain time after it is performed, otherwise no notice can be taken of such claims. In the accompanying specifications it is fixed by not allowing payment for any extra work unless it has been on a written order of the engineer. He has thus an opportunity of keeping a record of any work that may not be covered by the specifications, and has also an opportunity of fixing a price for it beforehand.

Some of the clauses in specifications are of doubtful use owing to their not being in accordance with the laws of contracts as held by the courts, so that wherever it is possible it is well to submit any specifications for their consideration by a lawyer well versed in such matters, and many times important changes will be found necessary and suggestions of great value will be obtained.

Great difficulty is sometimes found by a young engineer in writing specifications so as to conform to the many unforeseen conditions that may arise during the prosecution of a long contract. There are several good works on the subject that describe in a very lucid manner what is required, and a perusal of any of them will give valuable information. It is a good plan to make a collection of copies of specifications that have been found to work satisfactory, and refer to it when any similar works are required to be described. Then when any such works are being carried on, if notice is taken and recorded of where the specifications may be improved, a short experience will serve to make him quite an adept in such matters.

It will be found much more convenient to have the specifications of the standard pamphlet sizes 6'' x 9'', also for convenience of reference on the works to have them open, in note book form, at the end, and printed on but one side of the paper, than if they are of the usual "legal cap" form.

Marginal notes add greatly to their convenience, and when they are long, and time would be taken up in finding any particular clause at any time, an index could be added with advantage.

These things appear to be very trivial in their nature, but by paying attention to them a material difference will be found in the expedition with which work can be carried out, and also anything which tends to help a contractor will affect the way in which he carries out the contract.

SPECIFICATIONS.

Removal of old Sidewalks.

1. The corporation shall remove the old plank sidewalks, when it is necessary to do so, before the construction of the new walk can be proceeded with, but all stones, stumps, rubbish and other obstacles that may be encountered in the preparation of the foundation shall be removed by the contractor without extra charge, if not hauled more than one-half mile from the grounds.

All such material is the property of the town, and shall be disposed of as the engineer may direct.

Lines and Levels.

2. The proper lines and levels for the sidewalks to be constructed will be given by the engineer, and the contractor is required to preserve all stakes and bench marks unless permission is given by the engineer to remove them.

Excavations.

3. The contractor shall excavate to a depth of 10 inches below the level of the finished walk, and to a further depth than 10 inches, should circumstances require it in order to form a solid foundation. Any such excavation must be filled with gravel or other approved material, well watered, and rolled or pounded until quite solid.

The contractor shall be paid for this filling at the rate of 40c. per cubic yard when it has been previously ordered in writing, and duly certified to as correct by the engineer.

When the total excavation on any length of sidewalk extending along one block is greater than an average of 10 inches in depth, the contractor is entitled to an amount for such excess at the rate of 25c. per cubic yard, when it has been ordered in writing and duly certified to by the engineer, such excavation, however, not including the amount below the subgrade that has been excavated and filled, in order to form a solid bed, but that amount only that was necessary to bring the surface of the ground to the subgrade.

Foundation.

4. Upon the subgrade, excavated to as above, and filled so as to be uniformly solid, a foundation 6 inches in depth, of broken stone, clean gravel or other approved material shall be laid, thoroughly watered, pounded and brought to an even surface.

Concrete.

5. Upon the foundation thus prepared a layer of concrete shall be laid in the following manner: It shall be composed of one part of fresh Portland

cement of a quality approved by the engineer, and in accordance with the specifications for such as elsewhere described herein, and four parts of fine, clean, sharp gravel, free from clay, loam or dirt. The cement and gravel must be carefully measured and mixed while dry, then water must be added until the proper consistency is reached, and the whole must then be thoroughly worked over again. The concrete, when mixed as aforesaid, shall be immediately put in place and thoroughly rammed until it has an even surface, is perfectly and uniformly solid, and is 3 inches in depth over the foundation, and within 1 inch of the finished surface of the walk. It shall then be divided into blocks as the engineer may direct, and the joints shall be filled with clean sand, or other approved separating material.

Wearing Surface.

6. Upon the concrete layer prepared as aforesaid, and before it has had time to set, a wearing surface 1 inch in thickness shall be constructed. It must be composed of 1 part of Portland cement and 2 parts of clean, sharp sand or screened gravel of approved quality, which shall pass through a ⅝ inch mesh and be entirely free from clay, loam or dirt. The cement and sand or gravel must be mixed dry and then moistened, but it must be used as dry as practicable and be immediately put in place on the completion of the mixing. The layer must then be rammed or pounded and the surface worked so as to be true and even. A layer of best Portland cement must then be sifted over the surface to act as a dryer and to give a smooth finish to the walk, and the whole well trowelled to a perfectly even plane.

Slope of Surface.

7. The foundation, concrete layer and wearing surface shall be of uniform depth throughout the walk, and shall be constructed so that the finished surface shall have a slope of ¼ inch in 1 ft. towards the roadway, unless otherwise directed. The joints on the surface shall be cut to correspond exactly with those in the concrete and finished in a neat manner, and the edges of the walk must be neatly rounded.

Curbing.

8. Stone curbing, of dimensions and quality as approved by the engineer, must be set when required along the outer line of the sidewalk in an accurate manner and true to the lines and levels given. A piece of 2 x 6 pine, dressed so as to be perfectly straight on its edges, shall be furnished and set on edge along each side of the walk, before the concrete is put in place, by the contractor, and shall be removed by him after the cement has become hard. When removing the piece, sodding or other work that may have been done must not be injured, and the space left must be filled with good soil and neatly packed in place.

On street crossings a 4 x 6 white oak or cedar curbing shall be firmly fixed at each side in a permanent manner so as to protect the edge of the walk.

Openings.

9. The contractor must carefully fit the pavement around all waterworks, service boxes, coal shutes, down pipes, projecting steps, door sills, etc., and must take special care to prevent injury to any works or appliances that may be in or under the walk. Approved iron gratings, covers, etc., for areas shall be furnished the contractor by the town or owners of properties, and he must then place them, when so required, in true position to conform to the plane of the surface of the sidewalk.

Crossings.

10. At lanes and private driveways the edges of the walks shall be faced with the cement mortar used for the surface to the bottom of the concrete, and if

required the edges shall be rounded off and the surface marked in blocks or perforated to give a foothold to horses, as may be directed by the engineer.

On street crossings the concrete base shall be 3½ inches thick and the surface layer shall be 1½ inches thick and composed of equal parts of cement and screened gravel or sand, of a quality as aforesaid. The surface shall be rounded and finished as directed by the engineer.

Cement.

11. The cement used must be fresh Portland cement of approved quality and must conform to any or all of the following tests :

Tests.

(*a*) Its specific gravity shall not be less than 3·1.

(*b*) Not more than 12% residue shall be left on sifting through a No. 100 sieve.

(*c*) Make some parts of neat cement, about 2 or 3 inches in diameter, on pieces of glass, having the cement about ½ inch thick at the centre and with thin edges. Allow them to set in air and then immerse in boiling water for 48 hours. They must not show any signs of disintegration or cracking on the edges.

(*d*) The tensile strength after being pressed into moulds neat, and allowed to stand 24 hours in air and 6 days in water, must not be less than 400 lbs. per sq. inch.

The contractor must keep on hand a sufficient stock of cement ahead of his wants to afford a reasonable time for its proper examination and testing.

Period of Maintenance.

12. The contractor shall be bound to maintain the walks and crossings in perfect repair for the term of five years from the date of completion thereof, and should the contractor fail to do so at any time during the said term, then the engineer may do so and retain the cost of such repairs from any moneys due or becoming due to the said contractor, on this or any other contract, between the town and the contractor, or recover the same from the contractor or his sureties in this contract as money paid at their request. The certificate of the engineer is to be final as to the necessity of repairs and the amount expended in making them.

Drains.

13. The contractor shall be furnished sewer pipe, tile or other materials, and he must then lay any such drains for the carrying of surface or other water through or under the walk, as may be directed by the engineer.

Damages to Property and Lives.

14. The contractor shall make suitable and adequate provision for the safe and free passage of persons by or over the work while in progress, as may, in the opinion of the engineer, be necessary, and must confine himself to that half of the street on which the sidewalk is being put down, leaving the other half for the regular traffic.

He shall also put up and maintain such barriers and red lights and keep such watchmen as will effectually prevent any accident in consequence of his work, and he shall be liable for all damages in any way occasioned by his acts or neglect, or that of his agents, employees or workmen.

Foreman on Grounds.

15. At all times while the work is in progress there shall be a foreman or head workman on the grounds, and instructions given to such head workman shall be considered as having been given to the contractor.

Engineer.

16. Whenever the word "engineer" is used herein it shall be and is mutually understood to refer to the engineer of the Town of ——— and to his properly authorized agents, limited by the particular duties entrusted to them.

Non-rejection not acceptance.

17. Failure or neglect on the part of the engineer or any of his authorized agents to condemn or reject bad or inferior work or materials, shall not be construed to imply an acceptance of such work or materials if it becomes evident at any time prior to the final acceptance of the work and release of the contractor by the Town of ———.

Payments.

18. The contractor is entitled to 90% of the value of the finished work at the end of each fortnight, on the certificate of the engineer as passed by the Board of Works.

The estimate, so made by the engineer, shall not be required to be by strict measurement, but may, at the option of the engineer, be approximate.

The remaining part of the amount of the contract price, except any deductions that may, in accordance with the agreement, require to be made, shall be paid not later than ...., if in the opinion of the Town Council, on certificate of the engineer and Board of Works, the work is satisfactory, in good repair and in accordance with these specifications.

Notices.

19. The contractor shall give all necessary notices to telephone, telegraph or electric light companies, waterworks or gas officials, residents or owners of properties, and others interested, and must facilitate the repairing or building up of area walls for gratings, etc., such gratings to be put in place in the sidewalk by the contractor. These areas will be counted as solid in the payment for the walk.

Workmen.

20. The contractor must employ residents of the Town of .... in the prosecution of the work as far as possible, and the least rate of wages he shall pay to his workmen shall be 12½ cents per hour.

Conduct.

21. Any person employed on the work, who appears to the engineer to be incompetent or disorderly, shall on his requisition in writing, be immediately discharged, and such person shall not again be employed on the work without his permission.

Payment of Wages.

22. The contractor must pay his workmen's wages at intervals during the progress of the work, and unless satisfactory vouchers are furnished at the completion of the work that all wages have been paid, and if any remain unpaid at such time, upon the report of the engineer, the Town of .... shall have the right to pay such wages, and to deduct the same from any moneys due the contractor by the Town at such date of completion.

Rejected Material.

23. Any material that has been brought on the grounds, and which has been rejected on inspection, shall be wholly removed therefrom, and in case of non-compliance with this requirement within 24 hours of the time of rejection, the engineer may cause it to be removed at the contractor's expense.

Change of amount of work.

24. No claim for damages shall be allowed the contractor for hindrance or delay from any cause during the progress of any portion of the work, and any part of the work may be dispensed with, and the prosecution of the work stopped at any time, and no claim for damages will be allowed for anticipated profits on the work so dispensed with, or for any inconvenience the contractor may be put to by such cessation of work.

Order of work.

25. The contractor shall prosecute the work on the streets, and in order thereof as directed by the engineer, and he shall employ a sufficient force to ensure that the work on each street shall be completed within a reasonable time.

Sidewalks covered by contract.

26. The location and amount of the sidewalks to be put down under this contract are as follows.

STREET.	FROM	TO	WIDTH OF WALK.

Instructions to bidders.

27. All tenders for the work herein specified must be made on the forms hereto attached and none other will be considered.

28. As the guarantee of the good faith of the bidder, each tender must be accompanied by a certified check, payable to the Corporation of ...., for the sum of $100.

The check will be retained in the possession of the Town Clerk until the necessary contract and bond is entered into and the work commenced.

The checks of unsuccessful bidders will be returned within ten days of the opening of the tenders.

29. The Town of .... reserves the right to reject any or all bids, and the lowest bid may not necessarily be accepted.

30. The bona fide signatures of sureties must be given in each tender.

31. Tenders will be received until 7 p.m., ―――――――― 18......, and shall be sealed and addressed to the Town Engineer, and endorsed "Tender for Cement Sidewalks."

.... *Town Engineer.*

FORM OF PROPOSAL.

To...*Town Engineer.*

The undersigned, after having carefully examined the foregoing specifications, do hereby offer to furnish all the labor and material required, and to complete the work contemplated in the said specifications in accordance therewith, and to meet all the requirements under them of the Town of ...., and its engineer, at the following prices :

Cement Sidewalk at ....cts. per square foot.

Stone Curbing, 4 x 24 or over, from ....quarries .... at ....cts. per lineal foot, completed.

Street Crossings, with 3½ inch base, and 1½ inch wearing surface, 4 x 6 curbs at each side, at ....cts. per square foot of cement surface.

If the above tender is accepted we hereby agree to furnish approved securities for the construction and completion of the said work, and to execute the bond and contract therefor, in the form approved by, and when requested so to do by, the Town of ....

A marked check for $100 accompanies this tender.

....

Contractor.

Dated this ....day of..............................A.D. 1897.

We, the undersigned, do hereby offer to become bound with............ ....in a bond for $1,000 for the fulfilment of any contract for the works noted in the specifications as above for the laying of cement sidewalks, etc., in the year 18......, and for a guarantee of the substantial character of any work that may be awarded to them.

....

....

Sureties.

THE HIGH BUILDING PROBLEM.

By W. B. Mundie, F.A.I.A.

It would be futile in the short space of time allowed for this single paper to go very deeply into the science of high building and its relation to architecture.

Assuming you are not well versed on the subject from experience, but granting you have given it some careful thought from study and such sources attainable, I propose to confine myself as much as possible to the most salient features and conditions commonly met with in high buildings.

I do not wish to speak of the propriety of high buildings ; municipal laws should regulate this question.

Modern life and the customs of our people, their commercial spirit, together with quick-running elevators, inventions in heating, ventilation, electricity, sanitary and other practical conveniences, have imposed upon the architect this problem of high building. Architects as a rule are opposed to walling in the streets of our cities beyond a reasonable height, say twice the width of the street for suggestion. Some of our thoroughfares for several blocks resemble a canon in the Rocky Mountains, where the sun only shines for half an hour during mid-day.

In using the term " high building " I refer to the large commercial structures in the business centres of our modern American cities. The congestion of these business centres necessarily forces ground values to a high figure, and the land owner naturally looks for some way to increase the area of his holding without getting beyond the limits of lot lines. This condition primarily brought about the modern steel skeleton construction which made high building possible and profitable, though many minor difficulties and conditions had to be overcome to achieve success.

The sky-scraper has been ridiculed, but no doubt exists as to their necessity in order to meet a want urgently felt, and a want that will continue in our large cities as long as they continue to grow with a like rise in land values.

You will almost with one accord look at the commercial structure from the architect's point of view, and would probably pass judgment on an architect's ability from a single treatment of one of these structures.

There is another point of view, namely, that which the owner takes, and in most cases it involves the architect to the extent of whether he shall continue to be an architect of high buildings. A commercial building being a business venture is successful in ratio to its being profitable. These buildings are not built for glory; nor does an architect build them from choice; in fact, he can be very often seen at his worst in some of them. This percentage of profit is quite apart from architectural achievement. Few people spend great sums of money to purposely beautify a city. If it can be made a thing of beauty, well and good, but it must bring a fair rate of interest to its owner. Our high buildings would lack even architectural interest were it not for this fact that they prove safe and profitable ventures. No matter how bad the proportion of height to its width or base area, if it can be demonstrated that by the expenditure of a certain amount of money a building three times the height will bring profits proportionately greater, the question of good architecture is not considered, though our own impulse and feeling may be strongly against it. This vertical architecture is not beautiful to look upon, and we may regret it on artistic grounds, but if the owner is satisfied with the financial results, and that is what it was built for, then the critic should not find fault, for a building must pay, or no investor is willing to pay its cost. If the conditions under which high buildings are built could be understood or comprehended by the public, they would not be so quick to condemn. It is called ungraceful because it is so high; it is very plain, because of limitation of cost, etc. Remember the architect had nothing to do with the shape of the lot, nor the height, nor could he embellish the facade without increased expenditure. No architect is allowed to carry out these commercial ventures as he pleases. Invariably he is tied hand and foot by a series of conditions which he cannot alter in the least, and then held responsible by unthinking people for evils that are imposed by the problem. This commercial element may cause vexation to the artistic soul, but there is glory in being able to surmount the difficult conditions imposed. Think of what it has done for architecture within the past fifteen years. The development of the high speed elevator has been so perfected to enable us to carry up our buildings to any given height, bringing the fifteenth story on an equality with the fifth. All mechanical devices employed in constructive science have been perfected to respond to this commercial progress, and architecture is to-day greater and grander through this course of financial conditions, while our buildings are the wonder of other nations.

Architecture has always been an art of solving conditions and forming compromises to meet limitations, and thus the creation of a modern office building becomes as great a task as many a palace or cathedral. It renders practice more difficult and complex, possibly more of a business than an art, while it is certainly more a work of science in engineering. An architect can well pride himself in the perfection of one such structure.

Let us now consider the artistic treatment of one of these lofty structures. The problem is a strictly utilitarian one that confronts the designer. It must be solved in a manner or style possessing some artistic merit, and the difficulties to overcome are immense.

Where the conditions are more than ordinary, such as irregular shape of lot, or one far removed from well proportioned base lines, it is discouraging to a degree to almost baffle education. First aim to be simple, a most difficult thing to do in composition. Try to build in a natural way, adapting precedent to your conditions, but, above all, do not adapt whole features or parts of other buildings. Compose, but do not slavishly copy existing work. It is stealing pure and simple the work of other brains. I know of, and have seen buildings, the authors of which owe the public and the original artist an apology for breaking one of the Ten Commandments.

As the high office building is a series of cells, or offices in tiers or stories, the facade should interpret this interior condition, indeed it is hard to get away from it. The height of stories are alike, or nearly so, thus bringing all openings on a line horizontally, while office over office brings them one over the other vertically. Here is where the architect has to keep within bounds. The question of daylight is the most important ; it is the great essential feature in every commercial building in which the object is to provide the greatest number of rentable offices well lighted from the street. This presents a monotony, as the windows are numerous, and of similar size and shape. The windows are the all important feature upon the street fronts. The use of steel brought with it the use of large areas of plate glass. It has become epidemic in Chicago, and an immense amount of glass, many times more than necessary in some office buildings, has been the means of ruining the architectural effect. It is not necessary to have every office window a show window. Some object to the use of arch head windows in exterior treatment, because the circle cuts off some of the light. I know of one office tenant, when asked if he objected to the arch on that account, seemed surprised that his windows had circle-headed sash. He had been a tenant two years, and never raised his shades full height. Why curtail the wall surface to enlarge the glass area when tenants as a rule keep out one-third of the light with shades. Thus far we have outlined the utilitarian part of the problem, and now we reach the point of slow-going study.

We have no historic buildings of the past to turn to for grouping of windows, and contrasting wall surfaces for ornament, sixteen or twenty stories high. The designer must use here his own ingenuity and plan his attack. It is easy to leave these window-pierced walls plain, and the wall surface also, but you have a factory or warehouse. It adds but little to the task to decorate the wall surface, but this is not an artistic solution, it becomes decoration, and might be said to be "pretty"; it looks bald from a short distance, and suggests timidity. It is not architecture. Any good building looks well at all times, and from any reasonable point of distance. How can this be accomplished? First, try and contrast your openings as to size, space and grouping, then, if possible, combine some stories or bays as features or motifs; contrasting materials might be employed, together with ornamental detail, but let the detail be architectural. Use pediment, pilaster, cap, shield, base, architrave, key, or whatever your taste and instinct may prompt, as best for the place, and suitable to style. Avoid frivolous decoration of a wall paper or lace-like nature on an exterior claiming any pretence to dignity; it is not forceful architecture.

Now, we being the artist and the engineer together, for high building is engineering, even if devoid of all artistic claims, and the two make the architect—an engineer will tell you that architects waste material; they make things too heavy. We grant this to the engineer, for engineering, but it must possess beauty. A railroad bridge is ugly; so is machinery. Why? They are skeletons. Clothe your framework, and you have an ornamented bridge or machine.

A man can be an engineer and know little or nothing of architecture, but to-day a man can only be an architect by knowing a great deal about engineering—indeed it is almost essential that he should be an engineer. This has been brought about by the advance and change of materials in scientific construction. The old builders of cohesive construction were just as scientific, but the use of iron and steel was denied to them, except as jewelry for ornament.

Our ancestors have bequeathed us valuable examples of constructive form, but all in masonry, forms of construction which I have called cohesive.

To-day we have the skeleton construction. The manufacturers have come to the front with new materials, the liberal use of which it is ours to enjoy, and to such an extent as to be beyond the wildest dream of the old Roman, whose work was almost entirely monumental, and in this class of building we to-day honor him by sticking close to his time honored materials. Thus the architect has to design the entire work. It should look architecturally constructive, possessing architectural proportion with architectural materials, although its interior skeleton is mechanical.

The manner of erecting these structures is very similar. In general practice one building differs from another but little, except in detail. The cage or skeleton of steel is assembled story by story, each one independent and separate, having its own frame and covering, with only the weight of itself to support, and so framed that the outside covering of masonry can be started at the top, and built downward if necessary.

The present steel skeleton when first used had for its foundation the ordinary offset dimension stone footing. In Chicago the original surface level is of hard blue clay, very hard and tough. The streets of Chicago were raised so that the top of this clay is found about twelve feet below the street grade. This stratum of clay varies in depth, and will average ten feet thick. Below this is a spongy, sandy formation of about sixty feet, beneath which is another clay stratum before reaching rock. This rock will average about ninety feet below grade throughout the business centre. Pile foundations have been used to some extent, but buildings of this class always occupy a confined site, so that adjoining buildings have been seriously damaged by the pile driving. Besides, absolute safety demands, if piles are to be used, they should go to the rock. Our new public library, a very heavy building of cohesive construction, was founded in this way, rock being reached between eighty and ninety feet.

The nature of this compressible soil, with a shallow bed of top clay, prevented the use of stone footings, unless the basement could be given up for the use of the offset footings, while the weight of stone footings themselves is quite an item in the weight of a building. Thus the old method gave place to the new steel and concrete foundation, the steel skeleton being then complete in itself from bottom to top.

The cage is calculated scientifically to carry first its own weight, then the material covering of masonry, tile floors, and partitions, etc., together with the allowance for live load distributed on the floors.

The present building ordinance in Chicago permits 3,500 pounds per square foot on the clay, though many of the first planned buildings of this class were calculated for 4,500 pounds, and even more. This has proven too much, for some have settled badly and very unevenly.

Isolated piers in place of continuous footings are used so that the settlement can be controlled, though in many places where the footings overlap they are coupled in pairs on one increased footing.

This point of equality of settlement is extremely important. A building that shows settlement of eight inches, which is extreme, though some have gone more than sixteen inches, is nothing compared to one that shows a variation of five or six inches between maximum and minimum levels of piers. The former will show no cracks, while the latter will be racked and strained in parts, beyond calculation, and will show bad constructional cracks. Some high buildings have shown such variations as to cause uneasiness and call forth the question of safety, but where a building is honestly calculated, leaving out such short weight phrases as "take it for granted," "assuming this to be or that," weigh a building in its dead load as it actually is as near as possible, with proper allowance for wind pressure, and live load required, it becomes then a mistake in figures or negligence that permits any great variation of settlement. This short weight has caused much trouble. Our buildings are calculated with a factor of safety of four on the steel frame, and this is the fur-lined feather pillow that allows the engineer to sleep at night. Throughout the building numerous cross partitions are built on each floor all of different plans to suit tenants. They are not located when the foundations are put in. So it happens with toilet rooms containing heavy marble work and plumbing, corridors with heavy marble floors and wainscot, while the offices have none. Some architects allow this all to fall on the factor of safety, while the different piers become unequally loaded, and so on down through ten, twelve, or fifteen floors, until the bearing on the clay is but little better than guesswork. On account of the varied uses some of these buildings are subjected to, such as several tenants with heavy samples, in one end of the building, or probably a printing establishment with heavy vibrating presses, slight variations in settlement are expected, but extreme variation of settlement can be set down as an error unless gross abuse of the building by tenants can be proven.

This point of settlements in high buildings is a vital spot, that is, when built on compressible soil. If the foundation is upon solid rock or very unyielding hard pan, it is not so material, in fact, if on rock it would only be the crushing of the material.

Next to foundation in importance is the tying and bracing together at all points, making the skeleton one structure with no loose joints, taking vibration as a whole and not in any one part. Unless this is done and done well oscillation from wind will cause unequal straining of parts, even reaching to foundations in a heavy gale. At first it may not be of consequence, but continual loosening of the frame will cause damage at some future time. Every part strengthens a part and wherever a tie or fastening can be riveted on it is good practice to put it in. The reed in the river may bend and let the storm blow over it, but after a dozen floods it is far from being upright.

Wind bracing for the steel skeleton is of later development, and it is only within the last four years that it has been very thoroughly and scientifically applied to buildings. Each building for wind straining is in itself almost a different problem from any other on account of governing conditions, such as area of base, height of surrounding buildings, interior walls, light or heavy floor construction, etc. The maximum pressure being taken at forty pounds per square foot, a certain proportion, say one-fourth, or one-third, possibly one-half, may be taken by the buildings as constructed in proportion to the governing conditions, the balance to be taken up by special bracing designed either by gusset or angle plates at junctions of girder and column concealed in the exterior masonry walls, or by floor bracing on the corner bays of the building, or directly through the centre. Another form of wind bracing is applied as an angle or knee brace from the side of the column to bottom of girder projecting below the ceiling, covered in usually by a dividing office partition or segmental arch in plaster. Its application and design can only be determined by conditions, and is largely a matter of experience besides calculation.

We know that in a city where a good foundation can be counted on that the limit of height whereby these buildings can be made safe depends on the non-corrosive qualities of the steel and the danger from fire and earthquake.

The first of these requires more than ordinary precautions in building, and chemists are devoting time and study to rust preventative when metal is imbedded in concrete or masonry. At this time, in Chicago, the United States Post Office and Custom House is being raised to make way for a new structure. The iron beams are in an excellent state of preservation and the red lead paint in general looks as good as the day it was put on, but some parts have peeled off, and where this occurs you can invariably find rust underneath it, showing that rust had already formed before painting. Then again some beams show the ends built into the wall considerably corroded with rust ; these had been built in as they came from the mill, and the balance of the beam painted afterward before being inclosed. Another instance came to light last week where we are adding three stories to one of the first high buildings built in Chicago. The building fronts on two streets, one front in granite, the other in brick. The iron removed from behind the granite is perfectly sound, while the iron close to the face of the brick front showed signs of corrosion. This has only been in thirteen years, but it shows the brick absorbed the moisture and transmitted it through to the iron, while the granite was almost proof against it in ordinary weather. In demolishing a roundhouse here some few years ago the roof beams were found to be so corroded that you could push your finger through the web of the beam. These beams had been exposed to the combustion fumes and hot steam from the engines. Numerous instances can be cited where corrosion has reached a stage that would prove fatal to our buildings, but you can always find some substantial cause for it. That iron and steel will last in masonry for some time whether painted or not is backed up on every hand. A few years ago I picked out of the walls of Hadrian's villa, near Rome, the head of an anchor bolt that was still doing small duty holding marble veneer to the solid brick behind. The bolt itself was a mere thread, and deep in the brick could only be traced by iron dust, but the thick bead of the bolt was still alive, so to speak. The date of this structure, or structures, as it was built in parts, and at different periods, is given by authorities several centuries before Christ. The inference is that it was never painted, but it shows the material is lasting.

The best practice as followed to day is to coat the beams at the mill with linseed oil, then just before bricking in, to paint with graphite or red lead. This coat of oil is very necessary, as I have pointed out, and it is astonishing how it sticks to the metal. Unless a beam is free from rust before painting the rust will continue under the paint. I believe foundation beams put in in this way, solidly encased in concrete, will last centuries—longer probably than they will be called upon to do service. Protection from dampness as well as from fire must be sought after.

The second of these esential points, protection from fire, ought to be as near absolute security as can be obtained. I say ought, because many are not. Many buildings have thoroughly protected skeletons, but contain too much combustible material in trimming and furnishing. There is still much to be accomplished to eliminate inflammable material from fireproof buildings. They are comparatively safe from injury within, as has been demonstrated in several small accidental fires that have occurred in Chicago to prove it, and as a barrier to conflagrations, on the exterior, they are very valuable.

Fire engineers say that the covering of terra cotta or brick is liable to destruction from a furious heat suddenly cooled by water. This applies both to exterior and interior, and there is some truth in it. There are instances where it has peeled off, and exposed the steel work, but it has invariably shown careless and indifferent workmanship. This has caused many to scoff at the fire-proof building, and condemn the whole for the weakness of a part. Among this class you find some experienced firemen. A fireman is a bad critic on fire prevention; his business is fighting it, and he rests the whole case on the fact that a fire occurred. When a fireman criticizes a building in part or in detail, in regard to its construction, he is a safe man, and worth attention. It is only when these small imperfections and weaknesses are brought to the surface that the perfect can obtain. In the past ten years fires in any of our fire-proof buildings have been very rare. In fact, with one exception, they have never amounted to anything, and that one exception, the burning of the Athletic Club, was under circumstances that exist only during construction. It is seldom now that a fire in the business district of Chicago gets beyond the building in which it starts. The high building should never be built on the plan of what is known as semi-fireproof; it is an unreliable system of building, not without some merit in a building of seven or less stories.

High buildings are severely criticized by few, many buildings deservedly so, but whether it is approved or not, it has come to stay. It is the outgrowth of our present needs. The world will have buildings, and it will have them as it wants them. It demands all that scientific and industrial researches has brought forth in materials. It demands the use of steel, and in the architecture of our cities it will become more and more imperative. The future may demand larger and loftier buildings, and the architect must progress and fit himself for these duties before him.

NIAGARA FALLS SEWERAGE SYSTEM.

By J. B. Goodwin, B.A.Sc. (*Tor. Univ.*)

Introduction.—The subject of a "Sewerage System" is one upon which so much has been written that the writer would hesitate in presenting it before the Society, were it not for two reasons, which were deemed of sufficient importance to overcome such an objection, and it is to be hoped that something of interest and of possible benefit may result from the paper herewith presented, notwithstanding the fact that subjects of this nature are apt to be pretty well discussed.

One of the reasons which recommended itself in the design of the paper, and in the preparation of which was kept prominently in view, is the fact that the Engineering Society of the School of Science is essentially a students' body, the members of which form the basis of supply from which the practising engineer is taken, and therefore is not in a position to immediately adapt himself to methods of procedure in practice upon assuming responsibility. Some suggestion along the line of actual practice possibly would be of service to such a one.

It is not expected that the experienced engineer will be able to derive much benefit from the paper, and no attempt has been made to establish any new principle, or to point out any defects in the methods of modern practice.

The nature of the "outlet works" of this system also seemed to offer justification for presenting the paper, chiefly on account of the novel application of the "stave pipe works" in their construction. As far as can be learned there is nothing of a similar nature in any outlet for sewerage, at least in Canadian cities.

Description of Town and System.—Niagara Falls is an incorporated town of about 5,000 people, and comprises about 2.0 square miles within its limits. There is already a good system of waterworks, by which the Town of Niagara Falls and the Village of Niagara Falls (Drummondville) are supplied.

A system of waterworks must, for good sanitary reasons, be followed by a system of sewerage, and the problem of the disposal of the increased liquid wastes, due to increased use of water, emphasized the need of the immediate construction of a system of sewerage.

Previous to the construction of this system certain streets were sewered with pipes of various kinds and sizes. Where these proved efficient upon inspection they were incorporated in the system, and the cost of their connection with the system included in the estimate.

TOWN.—The town is situated on the west bank of the Niagara river, below the Falls, and is opposite the City of Niagara Falls, N.Y. The business position of the town is about 240 feet above the level of the river.

At the principal outlet of the system the current is especially strong, being but a few feet above the Whirpool rapids. It is admirably adapted for the disposal of sewerage without a possibility of stagnation.

ROCK.—Immediately at the cliff forming the banks of the river, the live rock crops out at the surface. Further up into the town depths of from twelve to twenty feet of clay were found. In this clay was found a layer of sand which, not being of an exact quicksand variety, yet upon excessive working, would become troublesome. This layer was from one to two feet thick, and did not prove particularly difficult in shoring up.

The rock here is the regular Niagara limestone formation—in some places soft and full of holes, while in other places hard, compact and flinty.

There is an elevation of rock outcrops near the Wesley Park locality, about half way between the Railway Suspension Bridge and the Falls. This forms a sort of hog's back from which the rock slopes both north and south, the total difference being in places as much as thirty feet.

Through the town runs a stream known as the Muddy Run Creek, whose normal summer flow is about 1.0 cubic feet per second.

FLOODS OF "MUDDY RUN."—During certain periods of the year, especially in the latter part of March or first part of April, the melting snow soon transforms this innocent looking stream into a veritable river, which overflows into the lower parts of the town, flooding business streets and over-running the yards of the G. T. R.

CULVERT.—This is due to a certain extent to the bad proportioning of culvert, which carries this stream beneath the town. It is built to join on to the culvert, built by the G. T. R., which carries it under their tracks.

The portion beneath the town was built as it was needed, and it goes without saying that the cross section is not at all uniform throughout. The smallness of the section at the entrance, compared. with that built by the G. T. R., the many subsidences and collapses due to bad construction, and the collection of debris in the many turns and angles, all go to make the culvert of little service.

SYSTEM.—Taking into consideration this portion of the creek, and other topographical features, whereby a suitable system of street grades could be established, to give quick drainage, either into this creek or the river itself, the " separate system " was recommended and adopted.

In one or two points this system was modified. Where it was impracticable to establish a grade whereby the street water could readily be taken into natural channels, it was more economical to place catch basins connected with the sewers of either the "separate" or storm system

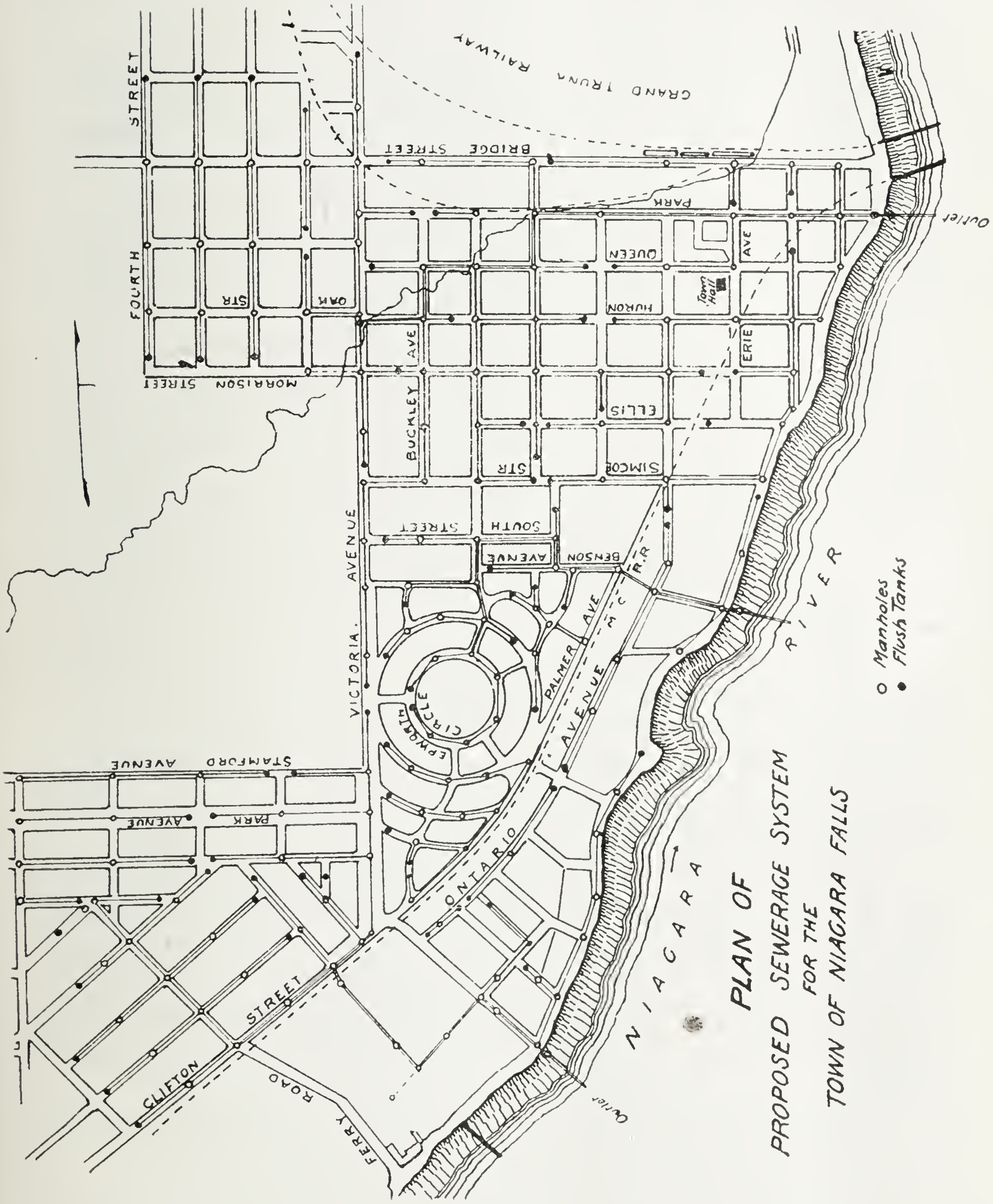
RELIEF OF " MUDDY RUN."—It was also necessary to relieve, in some way, the overflow of the creek. Even were the culvert taken up and replaced, yet in some places property would be overflowed. The building of a large brick culvert to replace the old was recommended as a means to partially relieve the flood. This will, in the near future, prove an almost absolute necessity. It was not, however, connected in any way with this sewerage system.

The size of the Park street trunk sewer was made four feet high by three feet wide and egg shaped, for the purpose of taking off part of this creek water, and was extended up the street to its intersection with the creek.

At another point in the " trunk " sewer an inlet was built which could be utilized for purposes of relief. This tapped the stream yet farther up.

OUTLETS.—The " outlets " for the system had to fulfil the requirements of the Queen Victoria Park Commissioners, the Provincial Board of Health, and the demands made upon them from an engineering standpoint.

The Park Commissioners required a covered conduit almost to the water's edge such that the natural scenery of the slope below the



PLAN OF
PROPOSED SEWERAGE SYSTEM
FOR THE
TOWN OF NIAGARA FALLS

cliff would not be destroyed; they, together with the Board of Health, required some plan whereby the sewage would be safely disposed of without rendering the banks filthy and unhealthful.

Provision was also to be made for a possible "low level" electric road.

For sewerage purposes the town was divided into three districts, the first and largest being relieved by the Park street outlet, the second by the Seneca street outlet, and the third by the Bender avenue outlet.

Park street outlet is situated about 150 feet south of the Cantilever railway bridge. The Bender avenue outlet is about one-quarter of a mile below the upper Suspension Bridge near the Falls, and the Seneca street outlet about midway between the two.

ESTIMATE.—Mr. Mitchell, in his report, estimated the complete system at $109,000—$40,000 of which was apportioned for out-outlets and brick sewers, the remainder for "lateral" system. The $40,000 is to be raised by general taxation, and the $69,000 by frontage tax of four cents per foot frontage per year for forty years, or seventy cents per foot frontage, payable down, or "commuted."

Frontage of corners assessed on both streets, but subject to an exemption of one hundred feet. Provision also made for triangular lots in gores.

The length of Park street brick sewer was 2,433 feet, and near its intersection with the creek an eighteen inch trunk line led into it. This eighteen inch line followed the general trench of the low levels of the creek, as near as the arrangements of the street would allow, and ended at a point near where the inlet, before mentioned, was built to connect with the creek.

In the Seneca street system there was also a short piece of two feet by three feet brick sewer made of this size, to relieve excessive street drainage, where, on account of private property and the embankment of the M. C. R., it is impracticable to dispose of otherwise.

The estimate for three outlets over the cliff was about $12,000. They were of similar design, varying only in sizes of pipes and inverts of tunnel.

Each consists of a shaft just inside of the tracks N. F. P. & R. railway, into which the brick or pipe sewer is built.

From the bottom of the shaft out to the face of the cliff a tunnel carries the sewage to a wooden stave pipe laid about six or eight feet underground, parallel to the slope of the bank below the cliff.

This discharges into an open channel at the bottom, the point of discharge being far enough back to permit the end of the pipe and the masonry anchor to be sufficiently removed from any possible danger from high water and ice jams.

Work of 1896.—The work for the year 1896 comprised the Park street and Bender avenue outlets and the trunk sewers relieved by them, together with a part of the lateral system. The Seneca street outlet, its trunk system and the remainder of the lateral system, will be finished during the coming season.

Last season's work was estimated at $19,000, which included engineering and inspection, and was divided into two separate contracts. The two outlets and the brick sewer on Park street, forming contract No. 1, and the pipe work of the trunks and laterals remaining, made up contract No. 2.

By-Law.—Mr. Mitchell's report was adopted and a by-law prepared to provide for the estimated amount. While the by-law was before the people, the plan of the complete system was exhibited in a conspicuous window for the purpose of giving the people some intelligent idea of what they were going to receive for the money so provided. Upon this plan were to be found the streets sewered, sizes of sewers, position of manholes, lampholes, flush tanks, inlets, etc.

Plan, location of outlets, position of prominent buildings, and the work covered by estimate, colored red.

It also showed the way in which provision was made for all possible additions to the system, these being colored blue.

The voters very much appreciated the effort to place before them something tangible on which to base their decisions.

The by-law was passed Jan. 6th, 1896, and Mr. Mitchell received the appointment of Engineer of Construction.

By-laws.—Two by-laws provided for two separate amounts : One for $40,000 for trunk sewers and outlets, and the other for $69,000 for laterals. By-laws also authorized the town to issue thirty-years debentures, paying five per cent., and the whole amount of interest and principal to be paid back in thirty yearly and equal instalments.

The time between the passage of the by-law and the beginning of operations was necessarily short, as the work was quite extensive, compared to the length of the season.

Preparation of Plans and Specifications.—In this time plans and profiles of all streets sewered had to be made, details of all parts of construction had to be prepared, and specifications, forms of contract and proposal sheets had to be arranged. Advertisements for tenders were put in "Engineering News" and Toronto dailies, and bids were received up to 12 o'clock noon of May 13th. Up to this time plans and specifications were to be seen and examined by the contractors who were bidding on the work.

Bids.—Fourteen bids were received on contract No. 1, and thirteen for contract No. 2.

The contract price of No. 1 was $18,203 on the basis of no rock trench excavation, and the contract price of No. 2 was $16,328.27 upon the same basis. For the purposes of comparing bids 1,600 yards of rock were estimated for No. 1, and 1,900 yards for No. 2. This made the bid of No. 1 $21,003, the price additional for rock being $1.75 per cubic yard, and No. 2 $19,653.27 (rock at same price).

Each bid was accompanied by certified check of $2,000, and satisfactory bonds equal to forty per cent. of contract price of the work bid upon.

Construction.—In this paper it will be impossible to enter into details of all parts in the construction, and only those features of greater interest and importance will be brought out.

Outlets.—Beginning with the outlets as a starting point for description, more space will be given this especial part, on account of the peculiar nature of design.

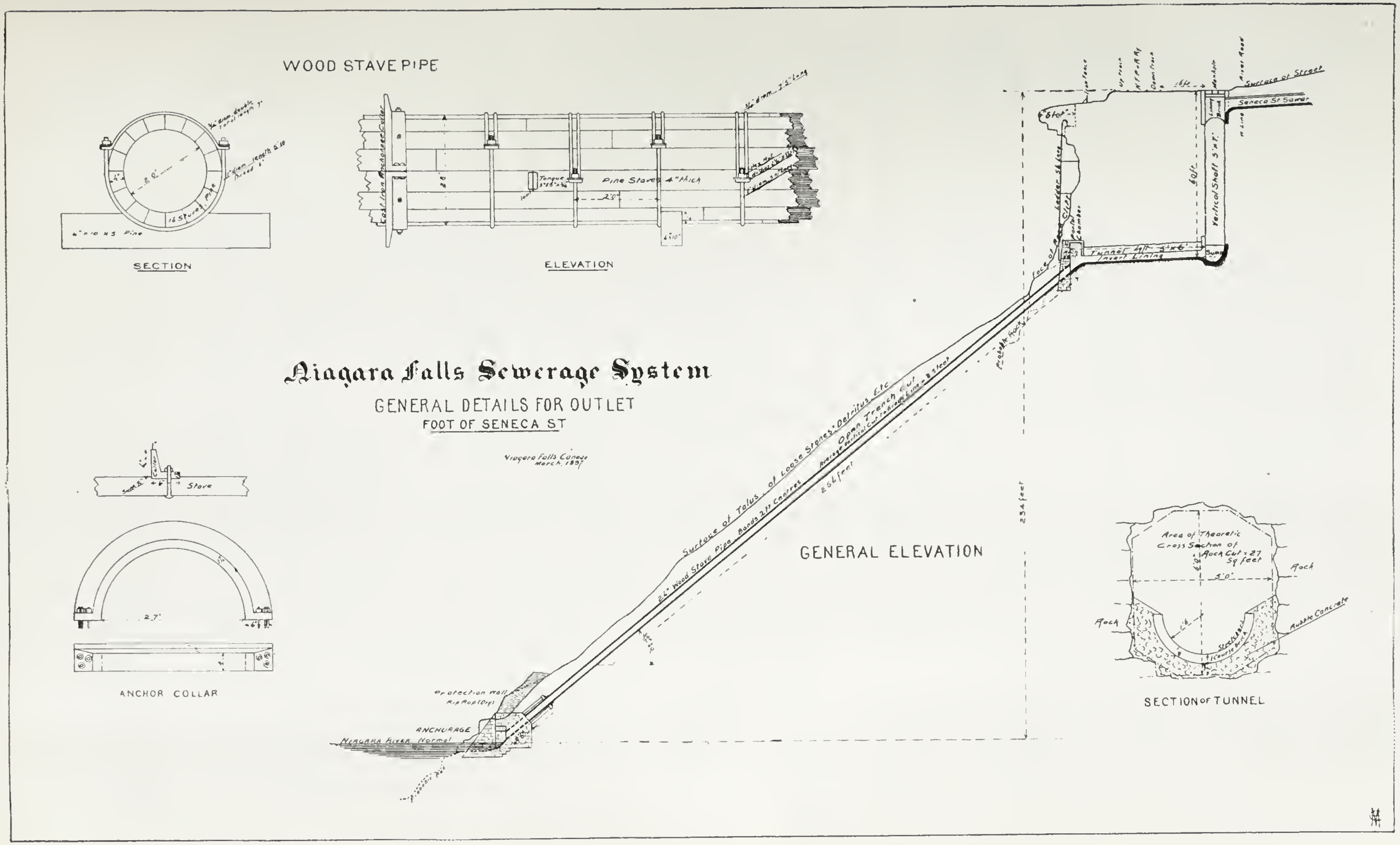
In addition to the requirements that these outlets had to fulfil, those of greater engineering importance were the "life" and "stability" under circumstances which were not at all favorable.

On account of the similarity of all the outlets the description of one will answer for all. The Park street outlet will be taken on account of its size, being the outlet for the overflow of creek waters.

A point was fixed upon far enough back from the water, and high enough up the bank, to be made safe from ice jams, and high water location of the masonry anchorage for the stave pipe.

In this case it was twenty or twenty-five feet back from the edge of the river. It was made of rubble masonry, into which were built two cast-iron collars which received the pipe. These collars were one inch less in diameter than the outside of the pipe. About eight or ten feet up the pipe was placed a third collar of the same shape and size.

A wooden frame of six by eight feet stuff was fitted round below the flange of the collar and struts placed between each corner of this rame and the masonry anchorage. The pipe was thus anchored



Niagara Falls Sewerage System

GENERAL DETAILS FOR OUTLET

FOOT OF SENECA ST

from slipping down at three points, the whole three depending upon the masonry in the anchorage. There were wing walls built to the masonry, on the river side, parallel to the line of the pipe and four feet apart. These were battered to receive the thrust of the pipe as nearly direct as practicable. Every precaution was taken in this connection to prevent any sliding of the pipe down the slope, whereby it would be broken away, at its junction with the invert at the mouth of the tunnel.

From the end of the pipe and between the wing walls an open channel was made leading to the river, which would have at least four feet water at low stages of the river.

A protection wall, of dry riprap, was built over to the anchorage in a V-shape to prevent any damage to the structure from masses of rock which periodically break away from the edge of the cliff and make their way to the river.

Pipe.—The pipe carrying the sewage from the tunnel to the channel at the river's edge was made of staves four inches thick, six inches wide on outside face and five inches inside. The inside diameter was three feet.

The specifications called for clear pine, planed on all sides, in pieces not less than fourteen feet long; of course in the constructions short pieces are necessary with which to start, as the joints could not be less than two feet apart. Wrought iron bands (made in two sections) were placed every two feet. One section was made of double three-quarter inch "round," bent and looped at the ends through which to allow the threaded ends of the other section to pass. The second section of the band was single, of one inch diameter.

With these bands every two feet the joints could be easily made water-tight, and brought to any desired degree of closeness.

These bands form a sort of templet that could be used in putting the pieces together.

Before the staves were allowed in the construction each one was subjected to one complete coat of preservative paint called carbolineum, and a second coat on the outer surface. After complete absorption the pieces were put together. All joints were fitted with white lead, and at the ends of each stave was a steel tongue 3 in. x 5 in. x 3/16 in. thick, which fitted into a saw cut made to receive it.

In this way the end joints were made rigid, and preserved from leaking and springing out of place.

Cross ties, 6 x 10 inches, by eight feet long, were spaced every ten feet apart under the pipe, and bedded solidly in the bottom of the trench.

These were placed against the lowest side of the wrought iron bands so that in case of the slipping of the bank there would be less danger of this sliding, and tending to carry the pipe with it.

Clear pine stave construction was chosen in preference to iron, chiefly because of its lightness and adaptability to the many possible changes of alignment and grade which the slowly sliding bank made quite probable.

No very serious effect of excessive velocity in a pipe of this kind could be anticipated in any case, as the scouring effect of running water upon planed wood is not very perceptible, and in any case the system being separate for the part, it is only occasionally that sand and silt would be carried. Another feature in which wood was preferable to iron was that of freedom from rusting, a very serious effect in such a position.

The length of the pipe was 254 feet and inclined at about thirty-six degrees, the total fall from the mouth of the tunnel to the normal water level of the river being 149 feet.

In the wall built at the portal of the tunnel another cast iron ring was placed, for the additional precaution against the slipping of the pipe down the slope.

Portal Wall.—This was eighteen feet high, eight feet wide, four and a half feet thick, battered to 2.8 feet at the top. The face of the wall was flush with the face of the cliff, the mouth of the tunnel being enlarged for this purpose. A brick chamber was built immediately behind, and bonded into the wall; this was for purposes of inspection, and also formed a means of entrance to the tunnel. An opening was made through the wall and over the pipe into this chamber, for which a hinged grating was placed, provided with lock and key.

In case of blocking in the pipe an elliptical shaped plate of iron was provided and placed so as to readily slide into place over the entrance to the pipe.

By this means the pipe could be cleaned or repaired without difficulty.

The opening in the wall over the pipe would in that case form a place of discharge during the repairs in the pipe.

LADDER.—From the edge of the cliff an iron ladder hung to a point at the base where it was anchored. At two or three places additional anchors were put into the face of the rock, and fastened to the rungs of the ladder.

This ladder was only accessible through a trap door provided with lock and key.

TUNNEL.—From the chamber at the "Portal" the tunnel led back from the face of the cliff to a point under the end of the brick sewer, a distance of about fifty-three feet.

This was given an inclination of about one foot in ten.

Its cross section was six feet high by five feet wide, less the corners, which made it twenty-seven square feet. This was about as small as could be conveniently worked and at the same time give a cubic yard per foot of tunnel.

The single coursed invert lining of brick was built, laid in best cement and backed by concrete. The radius of the invert lining was one foot nine inches and semi circular in form.

All loose or dangerous pieces of hanging wall were removed before the invert was built.

SUMP.--At the head of the tunnel and at the bottom of the shaft was a "sump" or silt basin, so contrived as to receive the impact of the falling water in its deepest part. The first aim of the "sump" was to deaden or render of less effect the fall of the sewage.

A longitudinal section in the centre line would somewhat resemble a spoon, the bottom of the "sump" being about three feet lower than the grade line of the invert produced back.

At the entrance to the tunnel, on the river side of the base of the shaft, was built an arched wall. This supports the junction of shaft and tunnel, and at the same time binds the brick work of the invert with that of the "sump."

The brick work of the "sump" is double coursed work of best vitrified brick laid as stretchers, with the courses transverse to the line of the tunnel.

The inside dimensions correspond with those of the shaft, five feet wide and seven feet long.

The brick walls are thus set back under the walls of the shaft.

SHAFT.—Size, 5x7 feet.—The depth of shaft required was fifty-six feet, and with the exception of the lining at the top, there was nothing needed to support the rock walls, which were of a substantial, solid formation, and no danger from crumbling or disintegration is expected.

Lining.—The lining at the top of the shaft extends about fifteen feet below the general level of the street. The walls are twelve inch brick work, built with Flemish bond.

The inside dimensions are five feet, two inches wide, by seven feet, six inches long, made so as to correspond to the general dimensions of the shaft, and at the same time to fit the standard shapes of buckle plates of which the covering was composed.

The original design called for these walls to be built on the ledges cut out of the walls of the shaft, but not being sufficiently careful in blasting the main dimensions of the shaft were enlarged, and no suitable ledges could be found for a safe foundation. Instead of having the walls supported at all points, four-ringed arches of brick were adapted, having the points of support in the corners of the shaft. Intersection with the brick sewer was made in one of the walls.

Covering.—Over the top are built eight-inch I beams and channels, set into the brick work, the top flanges being flush with the top of the brick work of the walls. These I beams and channels carry a buckle-plate construction filled in with concrete to the tops of the beams. Near one side of the shaft and between the two centre I beams an opening was left for inspection. Over this opening was placed a standard manhole cap, resting on the I beams; the top of which was the grade of the street. Over the whole floor and around the manhole cap is put the ordinary road metal, bringing the whole up to street grade. On the side of the wall near the manhole are iron steps, and on all sides are placed steps so arranged that a movable platform could rest upon them, which is used on examination or inspection of the sewer or shaft.

Brick Sewer Excavation Rock.—In the excavation for the rock trench for brick sewer every precaution was taken to prevent damage to property. Each blast was covered with a mat of logs securely chained together, close enough to prevent pieces from flying. No blasting was allowed within thirty feet of the finished sewer during construction, and where laterals were taken out for house connections in rock, the trench was excavated at least fifteen feet out from the edge of trench.

The maximum economic depth to which holes were drilled was about eight feet, and spaced from two to three feet, depending on the nature of the rock, a row being put in about six inches from the theoretical side of the trench. Holes were generally sunk about one foot deeper than the required depth of trench. Where the drill could be readily moved 100 to 150 feet of holes could be sunk per ten hours, ordinarily about 75 to 100 feet was the average. For 100 feet per day, and spaced two feet apart and holes six feet deep, the excavation corresponds to about twelve cubic yards per drill per day, taken out usually in benches of five or six feet.

EARTH.—Just above the Cantilever bridge approach the grade line left the rock, and no more was encountered for about 1,400 feet up the street. The excavation in earth was made more quickly, and all through the business part of the town the trench was in earth. The width of trench in earth was eighteen inches wider than external width of the brick sewer.

In this work the first two or three feet, after the macadam was removed to its separate place, was taken out by plough and scraper.

The average cut in this street was 11.5 feet to grade of invert.

In some places shoring was necessary, especially in deep cuts and where the bed of quicksand became bad by water leaking from water pipe or some old sewer pipe.

Small one-horse derricks were used to remove the earth from the trench, where the depth of excavation precluded economic handling by shovelling and staging. These buckets would hold from six to ten cubic feet of loose material, which was dumped into carts and taken back along the trench, or to some low points within the 400 yards limit of haul.

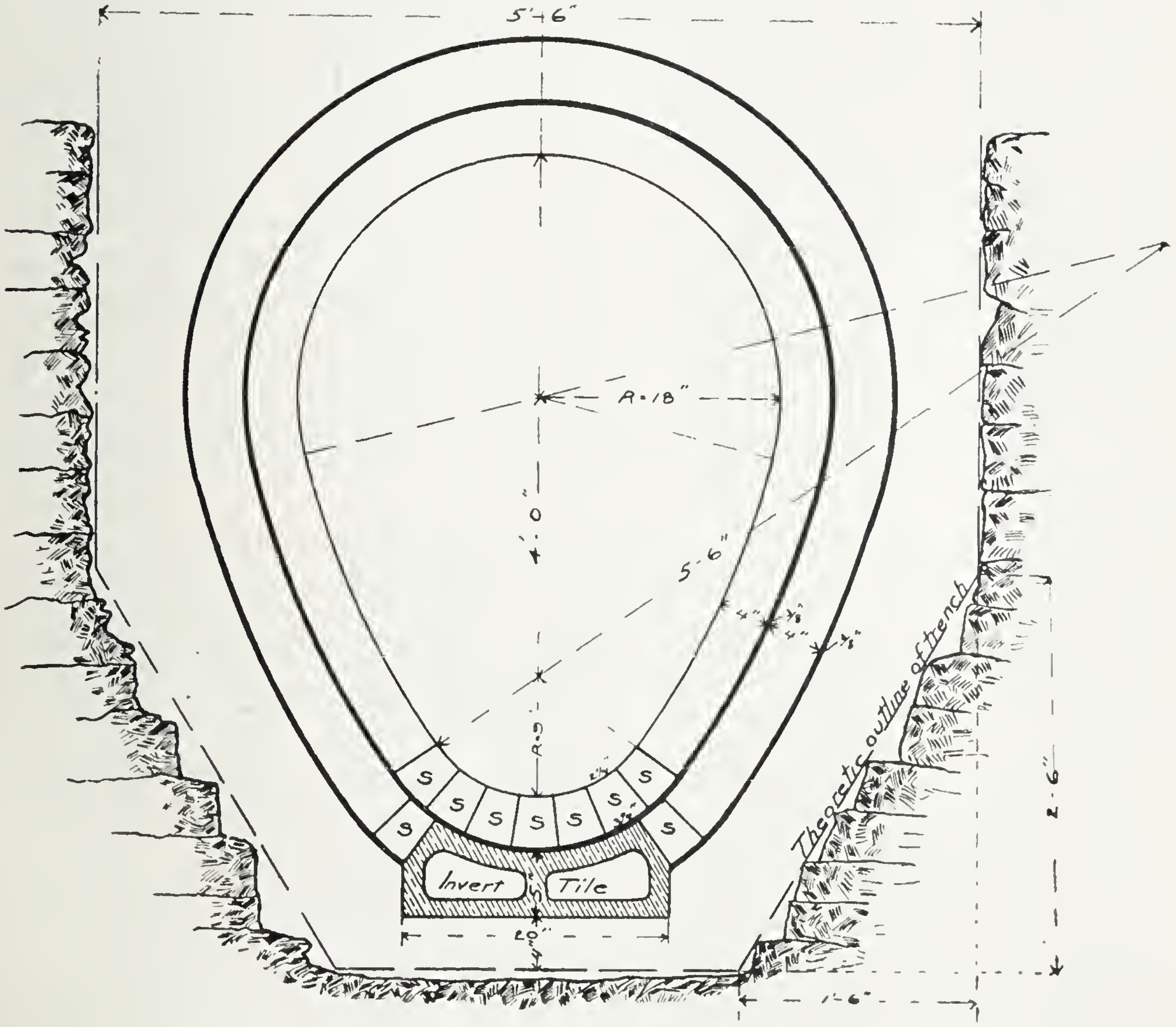
Not more than 200 feet of trench was allowed open ahead of the brickwork, and the back filling followed within 100 feet. Tunnelling in earth was provided for by special permission, in such places where the sewer crossed under the street railway or steam railway tracks.

The objection to tunnelling in general was that in backfilling the material cannot be sufficiently well rammed or tamped under the arch of the tunnel, and a consequent settlement takes place, which in time allows the whole arch to break away and fall in. In such places rigid inspection was enjoined.

BRICK SEWER CONSTRUCTION IN ROCK.—As before stated the size of the brick sewer was three feet wide by four feet high inside, with egg-shaped cross-section. It was made of double ring work of hard burned, best quality sewer brick.

The construction of such a sewer in rock requires close inspection and superintendence.

At the bottom the trench was shaped to suit the form of the sewer, i.e., at a point about three feet above the theoretical bottom of trench; each side was battered off to a point one foot and six inches from the side at the bottom, the trench itself being theoretically twelve inches wider than external diameter. Upon this basis was the amount of rock figured.



SECTION OF 3 X 4 BRICK SEWER—SHOWING TRENCH, SPECIAL BRICK AND INVERT TILE.

Note.—Outer course contains 54 Standard and 2 Special (S) bricks.
Inner " " 50 " " 7 " " "

The bottom of trench was to be $13\frac{3}{8}$ inches below the flow line, to allow: First, a bed of four inches softer material upon which to set the invert; next, five inches for the invert itself, and then $4\frac{3}{8}$ inches for the inner course of brick, and a collar joint of mortar.

The section of sewer was built with fifty-four brick in the outer course, and fifty in the inner; seven of the inner course being specials of size $2\frac{1}{4}$ x $3\frac{1}{4}$ by 8 x 4 inches, and two of the outer course being of the same pattern and size.

The tile invert was made of same material as the ordinary pipe, a salt-glazed vitrified clay with an admixture of fire clay. They were eighteen inches long, with a dividing partition along the centre.

These proved of great service during the construction by keeping down the water in the trench. The outer course of brick was started from the faces of this invert, which were corrugated.

Where the sewer was being constructed in rock a line of inverts was set to proper grade and bedded securely, and a "cradle" was made of such dimensions that the outside corresponded to the outside shape of the brick sewer at the bottom; this fitted down over inverts, and behind was packed with gravel or concrete backing, as the case may be, filling the corners and crevices up to the top of the cradle.

The cradle was then removed, and the work of laying brick commenced.

Lines stretched from the same templets as above guided the bricklayer. The ouside course would back up against the gravel filling that was put in behind the cradle. This insured a more solid backing than if tamped after the sewer was completed to the same height.

Bricks were laid with push joints with three-eighth inch collar joints, and three-eighth inch plastering outside.

With all conditions favorable three bricklayers could lay fifty feet of this sewer in a day.

Centres were not allowed out till at least two feet of filling was over the arch, and the work fairly well set. The time limit for this was at least six hours, but generally averaged ten hours.

Brick Sewer in Earth.—The construction of brick sewers in earth was similar in nearly all respects, with the exception that no extra excavation was required beneath the invert tile. Before the trench was firmly bottomed the sides and bottom were trimmed so that the outer course would back against it, as in the filling behind the cradle of the brick sewer work in rock.

Backfilling.—In backfilling over the sewer, the first two feet above the arch had to be spread and tamped in layers not exceeding six inches, and after that in layers of one foot in thickness.

Care was taken to remove shoring before the backfilling went too far, so that the vacancies could be well filled.

SLANTS.—Slants for house connections were placed at points convenient for use, and a wire attached to each, which was carried to the street surface.

Where the slant was over ten feet deep vertical pipe were joined to the slant to carry the connections to a point not more than ten feet from the street surface.

PIPE SEWER, POINTS OF JUNCTION.—As before intimated the pipe sewer construction was under a separate contract from that of the brick sewer and outlets.

CATCH BASINS.—In this system the introduction of catch basins was an economical necessity, in points were the natural drainage was not quickly enough effected. In one case the embankment of the M. C. R. along Clifton street prevented an easy means of taking care of the street water, and at two low points where the grades from either side met, catch basins were put in, and connections made to the sewer. At several other similar points this plan will also be followed.

FLUSH TANKS.—At the dead ends of laterals flush tanks were constructed. (See plan of system.) These periodically discharge a quantity of water that effectually keeps the sewer clean. In some places these flush tanks were combined in the construction with a manhole. These are special features of a separate system.

AGRICULTURAL TILE.—Another important feature in a system is the use of agricultural tile.

These are laid parallel and a little lower than the main sewer on boards about twelve feet long and six inches wide.

These tile relieve the general soakage of the ground, and give drainage to cellars, with which they are connected. The coming year considerable glazed tile will be used instead of agricultural tile, joints being caulked with hemp, but not cemented.

The accompanying table (page 54) shows the streets built upon, the limit of construction, sizes of pipes, length, appurtenances, etc.

The width of trenches in earth was specified to be twenty-one inches wider than exterior diameter of pipe, which gave sufficient room for tamping round and under the main pipe and the agricultural tile.

TRENCHES.—In rock the width of trench was twenty-one inches

Number	STREET	FROM	TO	SEWERS		MANHOLES	FLUSHTANKS	"Y" Con's		DRAIN TILE		SPECIAL	ADDITIONAL
				Size, inches	Length			4 Inches	6 Inches	SIZE	LENGTH		
1	Bender ave 1	Clifton st	Falls ave	15	816.5	3		18		5	840.5	1 lamp hole.	24 ft. of 15" iron pipe.
2	Bender ave 2	Falls ave	River Road	18	500	2		12		5	500		
3	Clifton st 1	Magdalen st	Centre st	9	858	1	1	23	2	4	858		
4	Clifton st 1	Centre st	Walnut st	12	872	2		24	2	4	872	1 catch basin.	
5	Clifton st 2	Walnut st	Bender ave	15	482.5	2		6		4	482.5	1 catch basin.	
6	Centre st 1	Lewis ave	McGrail st	9	360			8	1	4	360	1, 6" comb'd F. T.	10 ft of 9" pipe on Lewis.
7	Centre st 1	McGrail st	Clifton st	10	666	2		26		4	666		
8	Victoria ave 2	College Place	Jepson ave	8	677	1	1	40		4	677		
9	Victoria ave 2	Jepson ave	Simcoe st	9	755	2		50		4	755		
10	Simcoe st 1	Victoria ave	Buckley ave	10	424	1		16	1	4	424		
11	Buckley ave 1	Simcoe st	Morrison st	10	756	2		48		4	756		
12	Buckley ave 1	Morrison st	Huron st	12	360	1		8		5	360		
13	Huron st (Trunk)	Victoria ave	Superior ave	18	424	1		24		4	348	1 flush gate, det'l 3	72 ft of 18" iron pipe, or
14	Superior ave "	Huron st	Queen st	18	336	1		8		5	336	25 ft 9" con to St	concrete, beneath creek
15	Queen st "	Superior ave	Welland ave	18	746	2		52		5	446	L. complete 6"	100 ft of 4" glazed pipe.
16	Welland ave "	Queen st	Park st	18	345	1		34		5	345	con. to Welland	348 ft of 5" glazed pipe.
17	Chestnut st 1	Second st	Victoria ave	12	724	1		34		4	724	1, 6" combd F. T	
18	Victoria ave 3	Chestnut st	Huron st	12	1075	4		50	2	4	1075	30 ft 6" con com.	
19	Bridge st 1	Welland ave	Manhole	8	861	1	1	28		4	861		
20	Bridge st 1	Manhole	Erie ave	9	426	1		8	4	4	450		24 ft of 9" iron pipe.
21	Bridge st 1	Erie ave	Cataract ave	10	751	2		24	9	4	751		
22	Cataract ave 2	Bridge st	Park st	12	360	1		12		4	360		
23	Bridge st 2	Victoria ave	Welland ave	9	1060	2	1	62		4	1060		
24	Welland ave 2	Bridge st	Park st	9	329	1		8		4	329		48 ft of 9" iron pipes.
25	Huron st 2	St. Clair ave	Welland ave	8	414		1	24		4	414		48 ft of 4" glazed pipe.
26	Huron st 2	Welland ave	St. Lawr'nce av	9	421	2		24		4	421	1, 6", 1, 9" connect	

wider than interior diameter for pipes twelve inches and under; for over twelve inches the trench was eighteen inches wider than interior diameter. The depths had to be such as to allow six inches soft material to bed the pipe, and for pipes over twelve inches diameter the trench had to allow a bed of at least seven inches.

Where the grades were flat, cross-heads, for giving grade, were set every fifty feet, otherwise they were placed every 100 feet.

Laying Pipe.—The bed for the pipe having been prepared, the pipe is lowered in place.

Grade is given by use of a rod with a shoulder at the bottom, with sometimes an iron shoe upon it, and at the number of feet that the cross-heads are set a small cross piece is nailed; the distance between the top of the cross-piece and the bottom of the shoe being the number of feet that corresponds to the end from the cross-heads. With the shoe just resting in the bell end of the pipe, just laid and held perpendicular, the pipe is lowered or raised as the inspector gives the signal. With a piece of black paper on the small cross-piece on the rod, and white papers on the boards of the cross-heads, a well defined line is obtained.

While giving the sight for grade from one of the cross-heads the inspector can give the centre line by means of plumb lines, being from centres of the cross-heads.

Joints.—Having satisfactorily laid the pipe to grade and centre, the joint is partially completed. These joints are made with three or four strands of jute and cement mortar. The jute or gasket is first laid in the bottom of the pipe, against the shoulder, and a bed of cement holds it in place for about one-third way around. The pipe is then carefully put into place and forced tight against the shoulder. The ends of the jute are gathered up and rammed into place between the spigot and hub. The joint is then left till the next one is completed as far, and then it receives the cement mortar well pressed in and around the joint, and bevelled off, and the joint is considered finished. The cement mortar for pipe joints is made of one cement to one sand.

Construction of Appurtenances.—The appurtenances of the pipe system comprised flush tanks, manholes, combined flush tanks and manholes, lampholes, catch basins and inlet.

Flush Tanks.—The flush tanks were of the Miller automatic type, and were of two sizes—those with five inch and six inch siphons. The capacity of the flush tank with five inch siphon was

250 gallons, and were set to discharge every twenty-four hours. Capacity of six inch was 300 gallons, and set at same interval. These would discharge in a few seconds, and were found very effective and satisfactory.

The tanks were circular and plastered inside up to the water-line. The walls were single course brick walls laid as headers, and were brought up to receive a manhole cap, which was set to grade, and paved round with cobble stones.

Manholes.—In the standard manhole construction a foundation of six inch concrete was laid, upon which the brickwork was carried. Channels were formed in concrete between the incoming pipe and the one leaving the manhole.

Where four lines joined at one manhole the junction of the agricultural tile would have to pass beneath the flow line of the sewage from the main pipes, and take the form of an inverted syphon. The objection to this construction was the collection of silt at the junction of the four lines, which made it of questionable service.

It was found simpler and better in such a case to discharge the agricultural tile into the manhole through a trap built into the wall. The next line below could start at the manhole, with a plug put in the dead end, in which a hose could be inserted when flushing was needed.

Manholes were built as flush tanks with eight inch wall laid as headers, circular cross-section three feet six inches at bottom, tapering to two feet one inch at top, fitted with iron steps inside, and plastered outside. On the top was a standard manhole cap of height of ten inches, weight of head 350 lbs., and cover 130 lbs. This was paved round as was the flush tank cap.

Special Construction.—The crossing of the creek at different points, and the necessity of relieving the creek at high water, made special construction at these points a feature in the work.

Inlet at Park Street.—At the head of the brick sewer connection was made with the Muddy Run Creek for the purpose of keeping the water down during danger of flooding the lower part of the town. This took the form of masonry inlet with iron grating. It was located just at the west line of Welland avenue, on the line of the brick sewer. The inlet was made of substantial rubble masonry, with inside dimensions of four feet long and eight feet wide. The wall on the creek side was carried up to within four inches of the normal level of the creek, and a sill of eight inches high built on it. The wall opposite, into which the brick sewer was bonded, was four feet higher, and the side were walls built to suit the shape of the iron grating, which was carried from the sill in the front wall to a similar piece in the rear wall.

The area of opening, exclusive of grate, is twenty square feet. In the bottom is a silt basin two feet below the grade of the brick sewer. This collects silt and sediment, and may be cleaned out periodically.

At the time of writing this creek has risen to a very high level, owing to recent rains, etc., and the inlet has worked admirably, commencing to take surplus water as soon as it rises. By a system of stop-logs the whole creek may be turned into the inlet.

In addition to this relief inlet that at the end of the eighteen inch line also served as a relief, though as designed it is a flushing device, and built to receive the water at any level of the creek.

It was made of a single eight inch brick wall in the form of a chamber. The eighteen inch pipe is built into the two opposite sides, and the sewage is carried through the chamber through a half pipe. A partition wall divides this half pipe from a silt basin, into which the water of the creek flows upon opening the gate. The water flows from the basin over the partition wall and into the sewer, thereby serving the purpose intended. The level of the sill of the gate opening is six inches below normal level of water, and by raising the gate the whole ordinary flow can be turned into the system.

Special Manholes.—At a point in the Bender avenue sewer it was found necessary to adopt some special form of manholes in order to make a drop in the grade at a steep point in the street. It was impracticable to arrange a grade to overcome the difficulty without extra cost.

A special form of manhole was designed to meet the case. The incoming sewer was brought to a point about two feet away from the man-hole, and dropped outside the brickwork and entered the manhole at the base. This was accomplished by the use of a T pipe, one leg of which was carried on and entered the manhole about eight feet above where the outgoing pipe left. The sewage discharged down the stem of the T through two or three lengths of vertical pipe, and into the bottom of the manhole through a quarter bend.

Thus the grades of the two lines would meet about eight feet apart, and this construction thereby saved excavation, or if more breaks of grade were made, it saved another manhole or lamphole. This plan is also used extensively for smaller drops.

Combined F. T. and M. H.—The combined manhole and flush tank was simply a flush tank built alongside a manhole.

In all flush tank construction arrangements were made to flush the tile drains by simply pulling out a wooden plug in the bottom of the tank, and allowing the discharge to take place into the tile instead of through the syphon.

Sewers under Creek.—Special construction was also used where the lines crossed the creek.

Where the sewer was in rock ordinary tiles were used, and were surrounded on all sides with a six inch coat of cement. Where the excavation was in earth iron pipe of twelve foot sections was used, and four inch glazed pipe and cement joints were used instead of agricultural tile. Iron pipe was also used beneath railway tracks when crushing in of the pipes was quite possible.

Field Work in Connection with the Finished Records and Plans.—During the time the work was in progress data of various kinds had to be gotten for purposes of final estimate, records and plans.

As an additional price per yard was paid for rock excavated, levels were taken on the rock trench as soon as it was stripped. These levels were plotted on the profiles, and by the use of a planimeter the quantities could easily be calculated. These quantities were placed on this profile for record. The Y's for house connection were also recorded and plotted on the plan, showing size and location referred to the stationing on which the plan was based.

Old sewers, sizes and water pipes were also located and plotted on the same plan.

The data for assessment work was also a part of this finished plan.

The frontage of all lots on the streets where sewers were built was obtained. Location of houses, lot lines, sizes of triangles and gores had to be obtained and recorded. The finished plan would therefore show the sewer of the street, its size and length, location of Y's and their sizes, and the sides on which they were placed, old sewers, water pipes with sizes, lot lines, houses, frontages, position of manholes, flush tanks, lamp holes, etc. Thus a concise and complete record would be had in a convenient shape.

Inspection.—During the busiest time of the work, when eight or ten places were open at once, it required quite a number of inspectors. By good arrangement of the work five men were found sufficient to inspect all the points.

Inspectors were appointed upon recommendations by the engineer, and reported directly to him. They acted as his representatives, made reports of number of men daily employed, inspected pipes and all materials, and superintended construction.

MATERIALS.—The materials used in the whole work of both contracts were specified to be the best of their kind.

CEMENT CONTRACT 1.—Cement for No. 1 has to be equal to the best Canadian Portland cement, ninety-five per cent. to pass through a No. 50 sieve, and neat cement to stand two hundred pounds per square inch tension, after sixty hours in water with previous twelve hours in air, setting at a temperature of 70° Fahrenheit.

Sewer brick had to have a clear ring, be hard burned, and not absorb more than seven per cent. moisture by weight.

Sand to be clear and sharp.

Cement mortar used in brickwork was made of strength of one part cement to two of sand. The concrete used in this work was made of one part cement, three sand and three stone.

MATERIALS, CONTRACT 2.—In contract No. 2 cement had to pass a more rigid test for fineness—ninety per cent. to pass a No. 80 sieve. It had to show a tensile strength of two hundred and fifty pounds per square inch after sixty hours setting in air, with previous twelve hours in water at a temperature of 70° Fahrenheit. No absorption test required for brick. Sand and cement to be the same as in No. 1. Pipe had to be salt glazed vitrified, preferred in lengths of three feet. Size of hub and socket was to be of size to allow three-eighth inch joint all round. Sockets of pipes up to and including 9″ diam. were to be 2½″ top, and over 9 and including 3″ top with corrugations. Thickness of 18″ and 15″ pipe was specified 1½″, of 12″ 1″, of 9″ and 10″ ⅞″, and of 8″ ¾″.

PIPE.—Forty per cent. of each lot of pipe inspected had to be truly circular and of the remainder pipes of twelve inches and under must not show one-fourth of an inch divergence from being circular, and for pipes over twelve inches the divergence was not to be over half an inch.

Alignment was not to show a variation of over three-fourths of an inch in three feet. The pipes used were made in Toronto, Ont., of best fire clay, and proved a uniformly first class lot of pipes, fully complying with the specifications.

FINAL.—Many points in this paper have of necessity been only touched upon, and even with only superficial reference in many places, the paper has grown to the extent that is not warranted by the nature of the subject.

If it has grown somewhat lengthy, it has been made so from the attempt to make clear the different features of construction, thereby aiming to bridge the gap that seems to separate the theoretical and the practical.

Many points arise in supervision of work to which the theory of school training is not directly applicable, and these call for immediate decision on the part of the engineer in the work.

The interpretations of plans and specifications have often to be made on the spot, and this requires a quick appreciation of the results of the interpretation that may be arrived at.

The material attainable, the stability and efficiency of the arrangements so decided upon, are points that call for the quick exercise of originality and ingenuity of contrivance on the part of the engineer or his representative.

THE GAS ENGINE.

By R. W. Angus, Grad. S. P. S.

The following paper has been written more with the object of bringing before the members of the Society an engine which seems to be pretty much neglected in this country, than of bringing up anything new in regard to it. In fact very little theory has been touched upon, and what is here given is along the lines of the experimental work of Mr. Dugald Clerk, who perhaps has done more than any other person in England or America towards bringing out an explanation of the phenomena shown in this engine.

The efficiency of the engine and a few points in regard to the practical construction have been given.

If the paper should serve to awaken in the members an interest in its subject, the writer will feel well repaid for his work.

History of the Engine.—The history of the gas engine covers a period of over two hundred years, the first work being done by D'Hautefeuille in the year 1678. His invention, however, must have been very indefinite, as there seems to be little record of it.

In 1680, however, Huyghens built an engine in which gunpowder was employed. This was placed in a vertical cylinder under a piston and exploded, when the piston was driven to the top of its stroke. The gases in the cylinder were then cooled, and the difference in pressure between them and the atmosphere caused the piston to descend, and it was on this downward stroke that the work was done.

Barber, an English gentleman, secured in 1791 a patent on an engine operated by the explosion of a mixture of carburetted hydrogen and air, and used the direct effect of the explosion.

Robert Street seems to have been the next inventor, and it is interesting to note that he applied in 1794 the principle which was so successfully used in after years by Otto, the action being to allow the gas to explode under a massive piston which rose freely and did work on the downward stroke. The principle was poorly applied, however.

In 1799 Franzose Lebon made some inventions in this line, and seems to have had the right ideas, although his engine, like the others, did not accomplish much. He described the process of the distillation of carburetted hydrogen from coal, and used a mixture of this gas and air in his engine.

The engine was self-regulating and operated two pumps, the one for gas and the other for air, compression being performed in a separate cylinder, which communicated with the working cylinder, when the ignition and explosion occurred.

The next inventor was Samuel Brown, who, during the years 1823-26, secured several patents on an engine similar to that of Huyghens', in which work was performed by the excess of the atmospheric pressure.

The discovery in 1823 by Davy and Faraday, of the means of liquefying gases by pressure, and the fact that these liquids again formed the original gases when pressure was released, caused inventors to choose a new method for the operation of gas engines. An apparatus which depended upon the above facts was proposed by Brunel in 1825, and deserves some notice. He used five cylindrical vessels—*a b c d e*, Fig. 1—of which *a* and *b* are called *receivers*, and contain coils of pipes and also liquid carbonic oxide. These vessels, *a* and *b*, communicate, as shown in the figure, by means of two tubes with two intermediate vessels, *c* and *d*, called *expansion* vessels, partly filled with oil, and which in turn communicate with the bottom and top respectively of the working cylinder *e*, in which the piston moves.

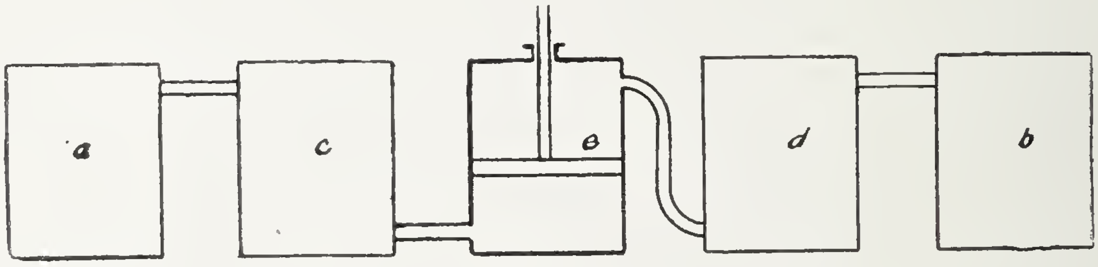


FIG. 1

If now hot water be passed through the coils in the vessel *a* and cold water through the coils of the other one *b*, there will be a considerable difference in the expansive force of the liquids in these vessels which will be transmitted by means of the oil in the expansion vessels to the piston of the engine causing it to move upwards. The hot and cold water supplies are then interchanged and the piston moves downward.

It is found that if water at a temperature of 120° be passed through *b*, the expansive force of the liquid would be about 90 atmospheres, while cold water in *a* causes a pressure of only 40 atmospheres, the difference, 50 atmospheres, being the working pressure. The reason of the failure of the engine will be obvious.

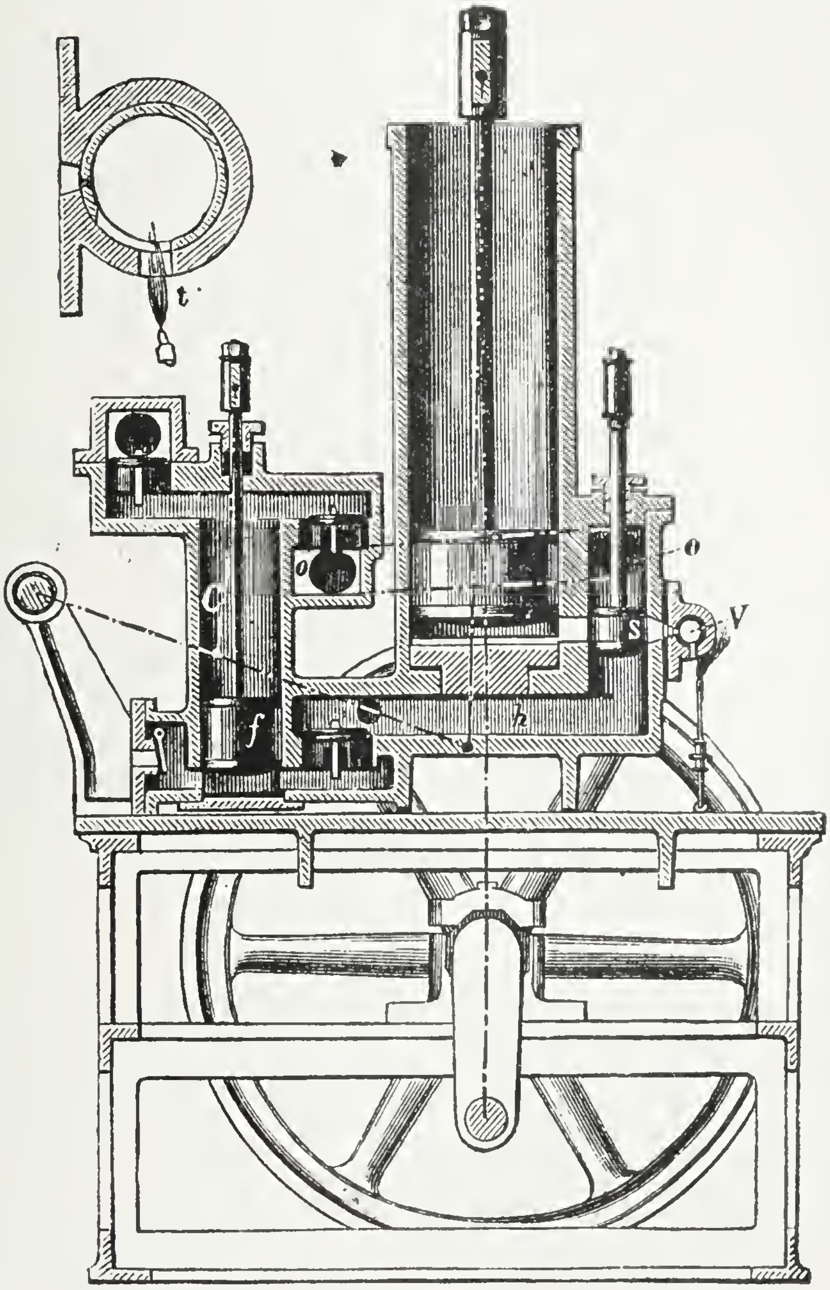


FIG 2.

Several other minor inventions now followed, although they all seem to have been on the principles of the earlier inventors, and Brunel's seems to have been the only one of any account of this class.

W. L. Wright proposed, in 1833, to draw into the working cylinder air and gas separately, then mix and ignite them, using the expansive force of the gases as in the case of the steam engine.

Cooper, in 1835, and Johnson, in 1841, ignited in their engines mixtures of hydrogen and oxygen which, after explosion, produced a vacuum and allowed the atmospheric pressure to perform work on the piston.

An engine invented by Sir J. C. Anderson in which gun cotton was exploded between two pistons, was not a success.

None of these inventors, however, had discovered the necessity of compressing the gas before its ignition, which is essential to the economy of all gas engines. It is true that William Barnet did, in 1838, invent three engines, (1) a single acting engine in which air and gas were compressed separately and mixed in the working cylinder and there ignited, (2) a double acting engine similar to the above, (3) an engine in which the compression occurred in the working cylinder during one stroke and ignition took place at the beginning of the next stroke, in which this principle was employed, yet he does not seem to have seen the economy of it and did not bring it successfully forward.

Barnet's single acting engine is shown in Fig. 2; *a* represents the working cylinder in which the explosion occurs, C is the pump for compressing air in the chamber *h*, while behind C is another pump compressing the gas in the same space. In its present position the piston valve *s* prevents communication between the mixture in the chamber *h*, the working cylinder *a* and the flame burning in the valve V. By means of suitable mechanism the flame in the valve V is allowed to communicate with the explosive mixture at the same time that the piston *s* moves sufficiently to allow the gas to communicate with the working piston, which is driven upwards by the explosion and the crank shaft revolves by means of the rods shown in dotted lines. When the piston reaches the top of its stroke, the flywheel draws it down and at the same time forces the piston *s* down far enough to allow the burnt gases to pass from *a* out though the pipe *o* into the pump C, from which they are exhausted into the atmosphere.

By means of a screw contrivance the flame is cut off from the working cylinder during exhaust.

Millon, the French inventor, and Schmidt, the German engineer, seem, however, to have been the first to show the advantage of compression. The former in his patent of 1861 says: * "In usual forms of engines the operation of the working cylinder is similar to that of pumps, the effect being to give two cylinders acting against each other, the pump even presenting higher resisting pressures than are found in the driving engine. The engines are thus made very large for the power produced. On the other hand, the engines working gases under the described conditions (pre-compression) will give great power in proportion to their size. The sudden firing of the gases compressed into the working cylinder gives the latter a much higher pressure than is perceived in the pumps."

We have now come to the point at which the gas engine began to be no longer a speculation, but a reality.

The first engine in practical use was the Lenoir, introduced in 1860. In this engine air and gas in proper proportions were drawn in during the first half of the stroke, when the admission was closed, the ignition caused by an electric spark and the gases did work by expansion during the remaining half stroke, and were expelled during the return stroke. An indicator card from this engine is shown in Fig. 4, and the engine itself in Fig. 3. Air and gas enter on the upper side of the engine, as shown in the figure, through a valve and ports in a similar way to steam in the steam engine. The exhaust takes place on the lower side through a valve, both the inlet and outlet valves being operated by eccentrics fastened to the crank shaft. The electric ignit-

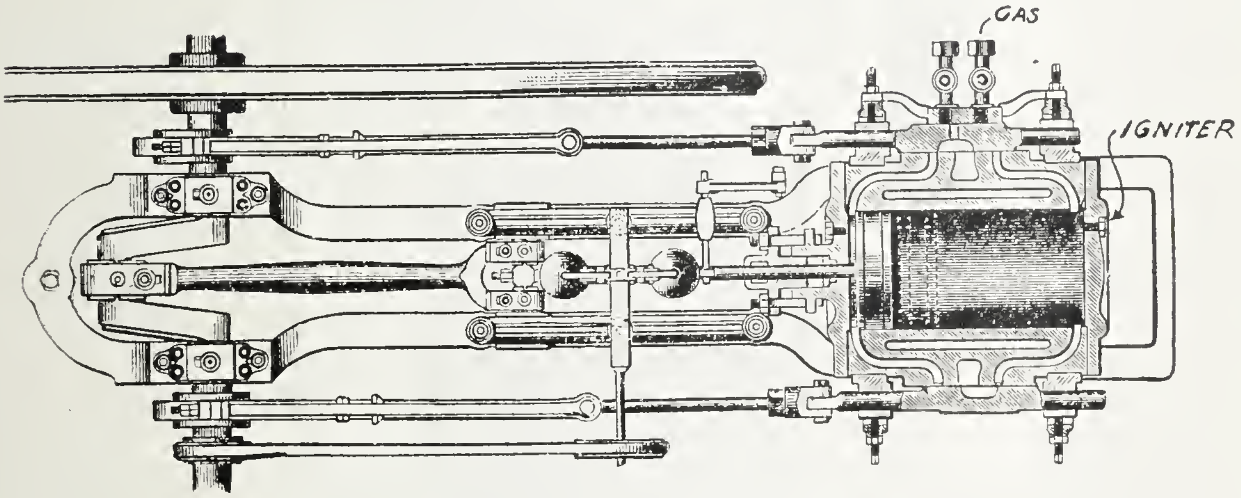


FIG. 3.

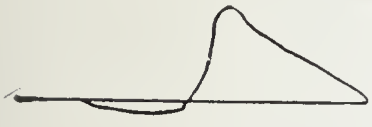


FIG 4

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* THURSTON—Heat a form of Energy.

ers are indicated in the two heads of the cylinder. No pumps were used in this engine, and the whole machine bears a striking resemblance to a steam engine in which the steam and exhaust parts are separate and on opposite sides of the cylinder. Compression was not used, and the heat taken off by the water jacket bore a large proportion to the total heat; the efficiency, therefore, was very low. The consumption of gas was about 95 cubic feet per horse power per hour, as against about 22 cubic feet in many engines at present in operation.

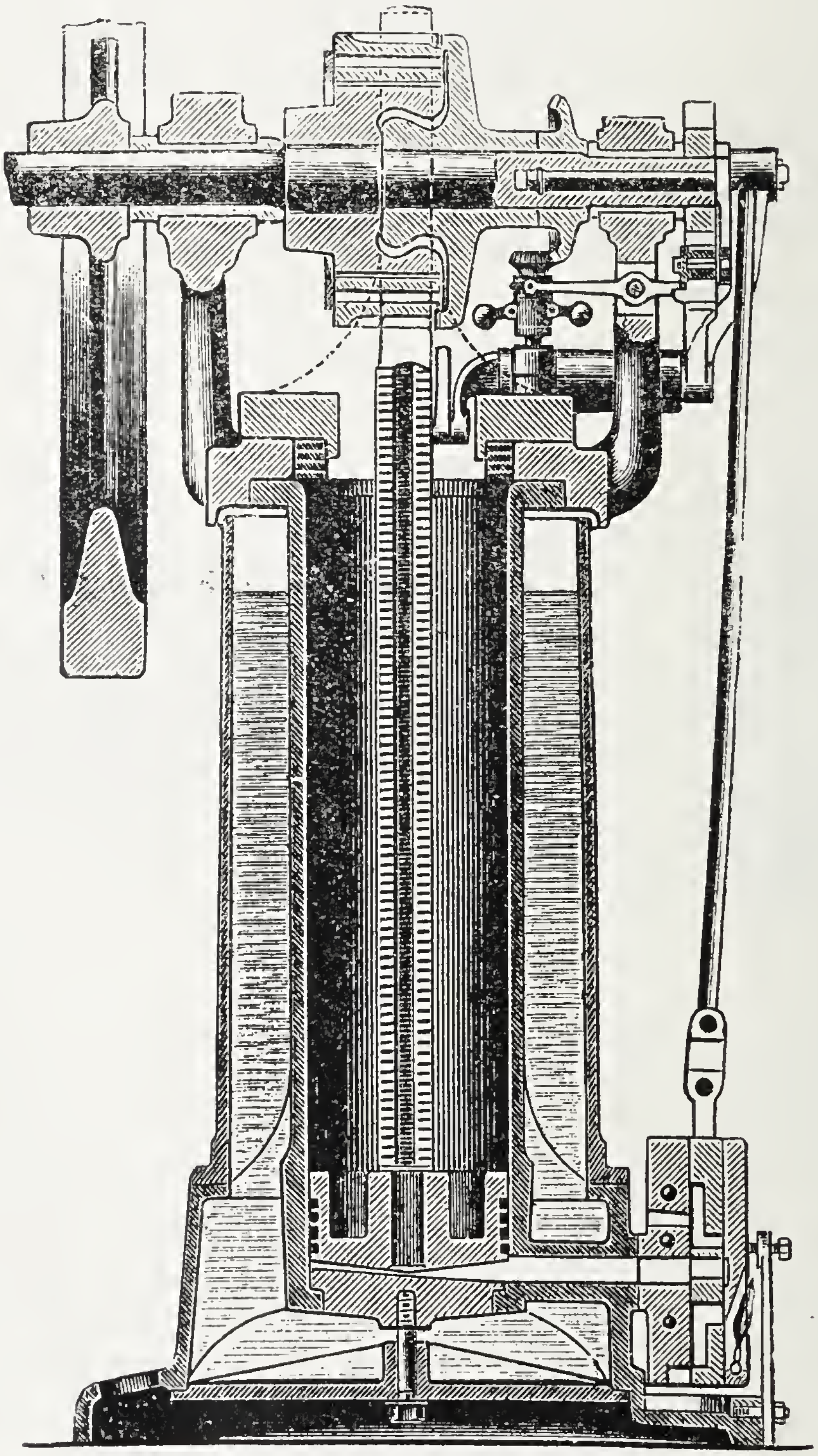

FIG. 5.

Hugon used a non-compression engine, with a jet of water for cooling. The only remaining engine of this type is the Bischoff.

The Otto and Langen engine introduced in 1866 used no compression, but was comparatively economical. The engine is shown in Fig. 5, and the working cylinder is vertical. Gas and air are admitted and exploded at the bottom of the cylinder, causing the piston to rise with great velocity without doing work. When it reaches the top of its stroke the water jacket cools and rarifies the gases and the atmospheric pressure and weight of the piston cause the latter to drop downward, during which motion it engages with the crank shaft and causes it to revolve, the burnt gas being discharged near the end of the down stroke. Fig. 6 is an indicator card from this engine, although Mr. D. Clerk points out * that it is incorrect, owing to the vibration of the indicator. This is readily seen, for the area below the atmospheric line must be less than the area above the line by an area representing twice the amount of work done in raising the piston ; *c* should therefore be nearer to the right hand end. The engine used about 40 cubic feet of gas.

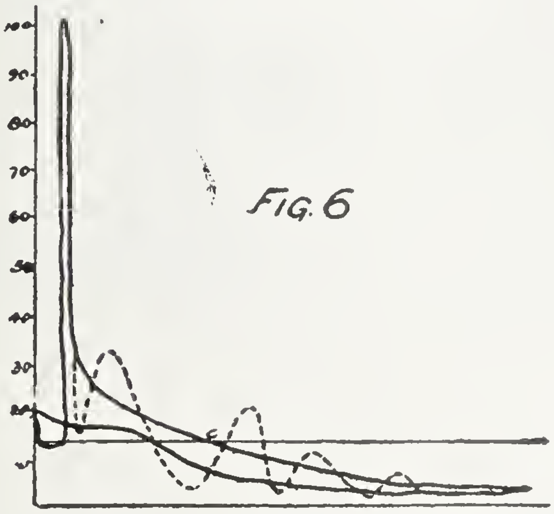

FIG. 6

The necessity of compression to economy had, however, again been brought out by Beau de Rochas in 1862, who suggested the four-stroke cycle engine, in which the gas and air are drawn in during the first forward stroke, compressed during the return stroke, ignited and allowed to expand during the second forward stroke, and the burnt products of combustion discharged during the second return stroke. He also showed that the conditions for maximum efficiency in this cycle were (1) the cylinders should have the greatest volume with the least amount of circumferential surface, (2) the speed should be as high as possible, (3) the cut-off should be as early as possible, (4) the initial pressure should be as high as possible.

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* CLERK—The Theory of the Gas Engine.

However his suggestions were not carried out till 1876, when Otto rediscovered the four stroke cycle, and invented his "silent" engine, which has now displaced all others.

The engine is shown in Fig. 7 and is horizontal. The piston is shown at the back end of its stroke, and the air and gas valves are open to the cylinder. The air and gas are admitted through ports in a long rectangular valve, which is operated by means of a horizontal shaft running at one-half the speed of the crank shaft, from which it is driven by means of gears. The mixture of gases passes into the cylinder during the first forward stroke of the piston and the admission is then closed, the gases in the cylinder being compressed during the return stroke. At the beginning of the second forward stroke a flame burning at C is allowed by the valve to communicate with the gases in the working cylinder, the ignition and explosion of these gases driving the piston forward. The burnt products are discharged during the second return stroke, and the cylinder is then ready for a new charge.

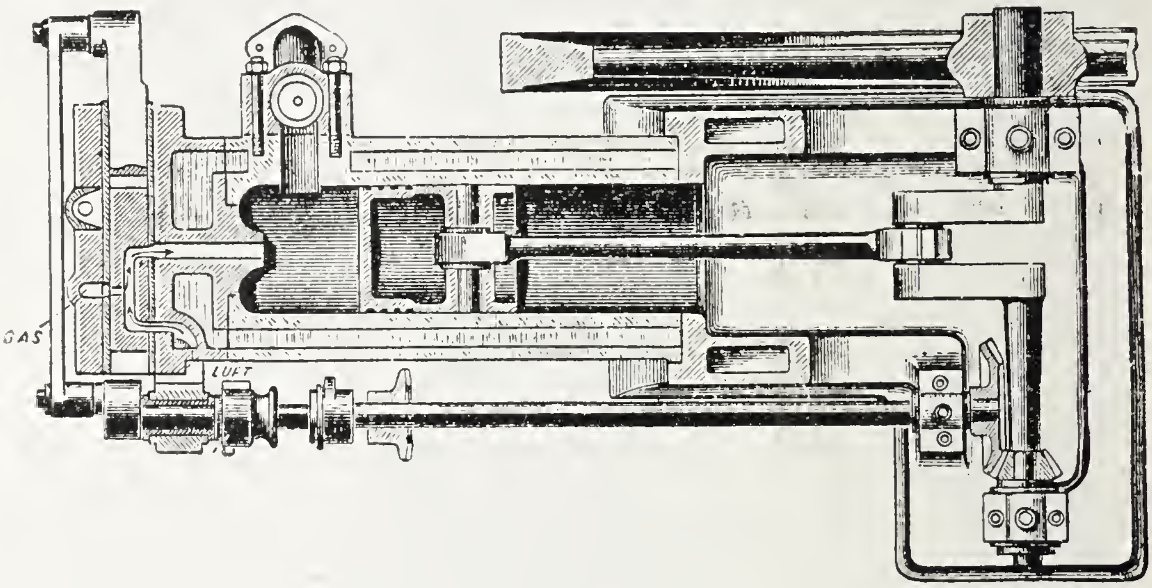

Fig. 7.

Atkinson endeavored to improve this engine by making the ratio of expansion greater than the ratio of compression, for in the Otto engine the exhaust temperature is high and the gases are still capable of doing considerable work when discharged. He used alternately long and short strokes, but the mechanical complexity was great and the plan has not been generally adopted.

THEORY OF THE GAS ENGINE.—Mr. Dugald Clerk classifies[*] gas engines in three distinct types: (*a*) An engine drawing in air and gas at atmospheric pressure for a portion of the stroke, then cutting off the supply and igniting the mixture, causing work to be done on the piston during the remainder of the stroke by the expansion of the burnt gases, which are exhausted during the instroke. This is similar to the Bischoff engine. (*b*) An engine in which air and gas are drawn in, mixed, and compressed in a reservoir. The reservoir communicates with the working cylinder and the mixture is allowed under a state of compression to enter the working cylinder, being ignited at constant pressure as it enters, and causing the piston to move forward. The burnt gases are discharged during the return stroke. (*c*) An engine in which a mixture of gas and air are compressed in the working cylinder and ignited at constant volume, thus causing the piston to move forward. The burnt gases are discharged during the return stroke. He has compared these engines theoretically under as near as possible their working conditions, and finds their efficiencies to be respectively .21, .36, .45. The compression engine igniting at constant volume having a decided advantage over the others, it is the only one which will be considered in this paper.

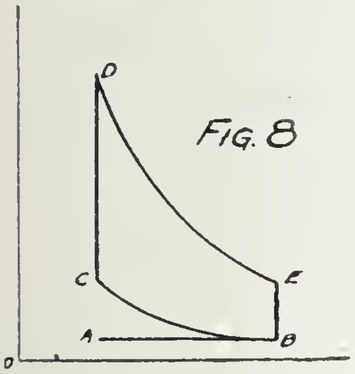

FIG. 8

The theoretical form of diagram for such an engine is shown in Fig. 8, in which O A represents the clearance volume and A B the volume swept out by the piston. A B is the admission at atmospheric pressure, B C the compression, C D the rise of pressure caused by explosion, D E the expansion line, and E B A the exhaust, the lines B C and D E being adiabatics.

It would hardly be supposed that the diagram actually obtained from the gas engine would show a close resemblance to the theoretical diagram on account of the water jacket surrounding the cylinder, which is known to take away a very great per cent. of the total number of heat units generated by the explosion of the gas.

There is a remarkable resemblance, however, between the actual and theoretical diagrams, and this led to considerable investigation of the subject, and the writer desires to insert the result of part of Mr. Clerk's work. He constructed an engine having a cylinder 6 inches in diameter and 12 inches stroke, and making 150 revolutions per minute. Fig. 9 is a diagram from this engine, which shows maximum pressure to be 220 pounds per square inch above the atmosphere, and that before ignition to be 41 pounds. The temperature before compression was 17°.3C., after compression 150°.5C., and that at maximum pressure was 1,537°C., at exhaust 656°C. The results obtained in a similar perfect engine, assuming the working fluid to be air, and that it is compressed to 40 pounds above the atmosphere and then suddenly raised in temperature to 1,537°C., he finds to be :

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[*] DUGALD CLERK—The Theory of the Gas Engine.

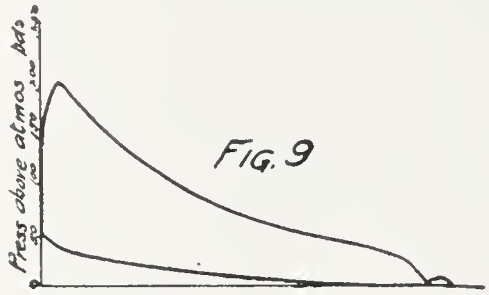

FIG. 9

1 cubic foot of air at 17°C., and atmospheric pressure at constant volume, requires to heat it from the temperature of 150°.5C. to 1,537°C., an amount of heat equivalent to	24,416 ft. pds.
Maximum pressure above atmosphere	220 pds.
Pressure at end of stroke, per square inch	49 pds.
Mean available pressure above atmosphere	89.8 pds.
Temperature at end of stroke	953°C.
Work done on piston	7,888 ft. pds.
Efficiency	$\frac{7888}{24416}$=.323

These results may be readily verified from the following data :

Specific heat of air at constant volume	0.169, water=1.00
Specific heat of air at constant pressure	0.238
Mechanical equivalent of heat in foot pounds, Centigrade	1,389.6
Weight of 1 cubic foot of air at 17°C. and atmospheric pressure	0.075 lbs.

The work actually done by the engine, as shown in the diagram, was, however, only 6,851 foot pounds per cubic foot of combustible, considering only $\frac{9}{10}$ of stroke, the mean effective pressure for this portion being 78.0 pounds, as against 89.0 pounds per square inch on the theoretical card. The calculated duty of the engine was thus $\frac{6851}{24416}$=.28. Now, taking ordinary samples of coal gas he found that 3.92 cubic feet would, if its whole heat were converted into mechanical work, develop one horse power per hour. The *calculated* consumption of gas was then for the theoretical diagram $\frac{3.92}{.323}$=12.1 cubic feet, for the actual diagram $\frac{3.92}{.28}$=14.1 cubic feet, and the actual consumption by experiment was 22 cubic feet. While then the difference between the actual and theoretical *calculated* efficiencies from the diagram is only small, yet the *actual* difference is great. Now the number of cubic feet of combustible required per H.P. per hour by the engine is $\frac{1980000}{6851}=289$, so that for each cubic foot of combustible mixture there is $\frac{22}{289}=.0761$ cubic feet of gas, while in the perfect engine there would be required but $\frac{12.1\times7888}{1980000}=.0483$ cubic feet. It would, therefore, appear that while the actual diagram would indicate an efficiency only 4 per cent. below that calculated from the theoretical diagram; yet the actual difference is much greater than this, and the actual efficiency is only about 55 per cent. of the theoretical. It is quite evident, then, that the amount of heat passing between the cylinder walls and the outside, and hence the efficiency of the engine, cannot be found by comparing the theoretical and actual diagram. "This fact was first pointed out by Prof. Rücker, of Leeds, and does not seem to have been noticed by early experimenters, so that results given by them as to efficiency are considerably too high."*

Authorities on the gas engine seem to differ as to the cause of the phenomena above noted, some of them affirming that they are a result of slow inflammation of the gas. The gas, they maintain, is only gradually ignited; as the piston moves forward the heat added by the slow ignition keeps up the pressure.

Mr. Clerk, however, does not agree with this explanation, and his objection seems to be sustained by the results of experiments made on various mixtures of gas and air, the proportions ranging from 1 of gas to 5 of air, to 1 of gas to 15 of air. When the ratio was 1 of gas to 6 or 7 of air the best explosions resulted, and it was found that maximum temperature and pressure, which Mr. Clerk maintains indicate complete ignition, occurred in $\frac{1}{20}$ of a second after the light was applied, and that the maximum temperature was only 1,800° C., instead of a calculated 3,800° C. Having known also that the high temperature immediately after ignition would prevent complete union of the gases, led to the conclusion that the phenomena observed in the engine were not due to the slow ignition, but rather to the fact that the gases only gradually united as their temperatures sufficiently decreased.

However, although this latter theory may serve as a partial explanation, it does not seem to be the real reason, for these results are noticed more in engines in which the explosive mixture is weak in gas, the temperature therefore comparatively low, and its effect on the combination of the gases small.

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* CLERK—Theory of the Gas Engine.

The matter therefore requires further investigation.

Otto at first thought it important to have the mixture in the engine stratified so that a part rich in gas should be first ignited, which would readily ignite the rest. It has, however, been shown that this is entirely unnecessary, and that as good results are obtained in well mixed mixtures. It should, however, be borne in mind that ignition is more easily effected in a mixture rich in gas than one poor in gas, so that care should be exercised to place the igniters in such a position as to be in contact with fresh gas and not with the burnt gases from the previous explosion.

The distribution of heat in the Clerk engine was as follows, as may be calculated from data already given on assuming that gas produces on complete combustion 505,000 foot pounds. (Since there is only .0761 cubic feet of gas present per cubic feet of mixture, the heat evolved will be .0761 x 505,000=38,430 foot pounds.)

	Foot pds.	Heat units per cent.
Work done by 1 cubic foot of the mixture	= 6,851	17.83
Mechanical equivalent of heat discharged with the exhaust (= {656—17} × .075x1,389.6 × .169)	= 11,253	29.28
Mechanical equivalent of heat passing through the sides of the cylinder (by subtraction)....	= 20,326	52.89
Totals	38,430	100.0

That is, for every 100 heat units given off by the explosive mixture, 29.28 are given off in the exhaust, 52.89 are lost in heating the water in the jacket, and only 17.83 are converted into useful work.

Efficiency of the Gas Engine.—The efficiency of the cycle is measured by the ratio of the work done by the gas to the total quantity of heat supplied.

Referring to Fig. 8, since BC and DE are adiabatics the work of expansion will be

$$W_{DE} = \frac{v_D p_D}{k - 1}\left\{1 - \left(\frac{v_D}{v_E}\right)^{k - 1}\right\}$$

and the work done on the fluid during compression is

$$W_{CB} = \frac{v_C p_C}{k - 1}\left\{1 - \left(\frac{v_C}{v_B}\right)^{k - 1}\right\}$$

and Q, the total heat supplied in foot pounds, is given by

$$QA = C_V (T_D - T_C).$$

Where p, v, T are respectively the absolute pressures, volumes and temperatures at the points indicated by the subscripts; k is the ratio of the specific heats of the gas; C_V is the specific heat at constant volume, and A is the reciprocal of Joule's equivalent.

But $v_D = v_C$ and $v_B = v_E$ and $p_D T_C = p_C T_D$.

Hence the efficiency E is given by

$$E = \frac{\dfrac{v_D p_D}{k-1}\left\{1 - \left(\dfrac{v_D}{v_E}\right)^{k-1}\right\} - \dfrac{v_C p_C}{k-1}\left\{1 - \left(\dfrac{v_C}{v_B}\right)^{k-1}\right\}}{\dfrac{C_V}{A}(T_D - T_C)}$$

$$= \frac{\dfrac{A v_C p_C}{k-1}\left[\dfrac{T_D - T_C}{T_C}\right]\left[1 - \left(\dfrac{v_A}{v_B}\right)^{k-1}\right]}{C_V (T_D - T_C)(k-1)} = 1 - \left(\frac{v_A}{v_B}\right)^{k-1}$$

Actual Construction of the Engine.—Engines such as the Otto, Fig. 7, are made single acting, and are of very simple construction. The cylinder is of cast iron and has a water jacket cast on to it, which, in the performance of the engine, is supplied with a stream of water.

The cylinder has no head in the crank end, and no crosshead is required, as the piston, being made of an extreme length, serves the purpose of guides. The volume of the cylinder and volume of clearance are usually so proportioned that the pressure, after compression, is about 35 pounds per square inch above the atmosphere.

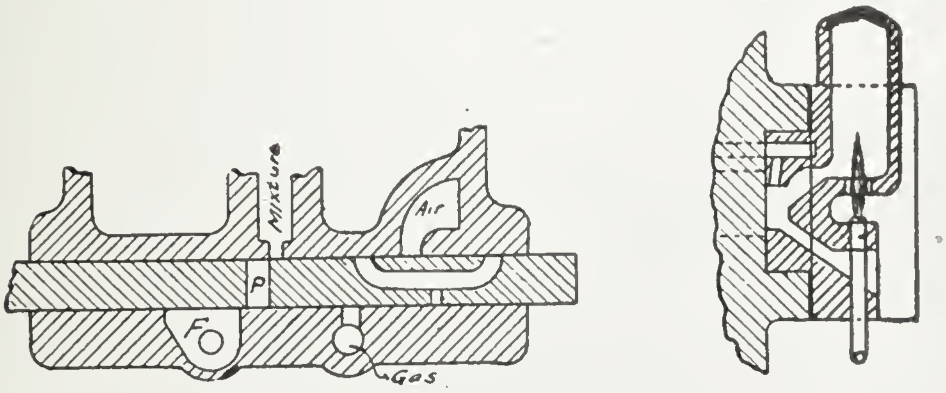

FIG 10

The gas and air are admitted as shown in the figure, the inlet valve being of rectangular shape and operated through the horizontal shaft, driven from the crank shaft by means of a bevel gear and pinion, reducing the velocity in the ratio of two to one. A large section of the valve is shown in Fig. 10. The spaces marked "gas" and "air" are respectively connected with the supply of gas and the atmosphere; as shown in the figure, admission is taking place, the gas and air passing into the valve, mixing as they go, and the mixture is passing into the cylinder. The valve remains open for one full outward stroke of the piston, during which it moves over enough to the left to close the parts at the end of the stroke, so that compression may occur in the cylinder on the in-stroke of the piston. The valve now continually moving over to the left, brings a port, P, in contact with a flame which burns at F, and this port, carrying the flame with it, passes over till it communicates with the cylinder and ignites the mixture. In the valves a small hole is drilled from the port P to the inner face of the valve, which comes into communication with the cylinder just after P has passed away from the flame F. This small hole conducts the compressed gas from the cylinder to the flame in P, and the pressure in this port is thus raised very high on account of combustion of the gases, so that the flame shoots forth, igniting the whole mixture in the cylinder as soon as the valve reaches the proper position.

In all gas engines the gas is admitted through two valves before entering the engine, and is not in communication with the slide valve until the outer valve is opened.

This outer valve is placed directly at the end of the gas pipe and is operated usually through the governing mechanism, so that in case the engine runs above normal speed this valve will not be opened, and consequently a fresh charge will not be admitted to the cylinder, although a charge of air is of course drawn in at each fourth stroke.

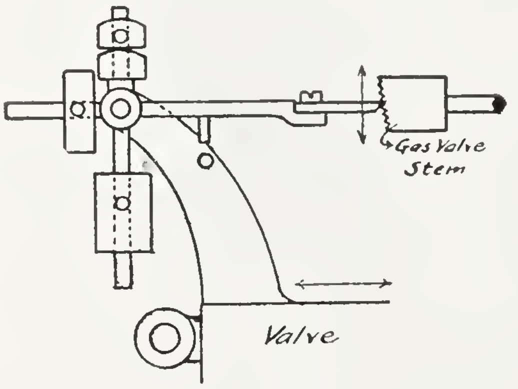

FIG. 11

The governor for this type of valve is shown in Fig. 11, and scarcely needs any explanation. It is a pendulum governor, and when the speed is normal, hangs in such a position as to open the gas valve at each stroke of the inlet valve, the governor being attached to the latter. If, however, the speed is excessive, the weight flies out, and the small lever being drawn down misses the valve and a charge of gas is not admitted, and consequently no explosion occurs for the succeeding stroke of the piston.

INLET VALVES.—In some cases, however, and they are not few, the inlet valve is of the kind known as the "poppet" valve shown in Fig. 12. In most of these cases the velocity ratio between the crank shaft and valve motion is obtained by means of a spur-gear and pinion. The pinion is keyed to the crank shaft and a pin is put on the gear wheel, to which a rod is attached, and which consequently has the motion of the connecting rod of an engine. The end of this rod striking against the end of the valve, causes it to open, and it closes of itself by means of a spring.

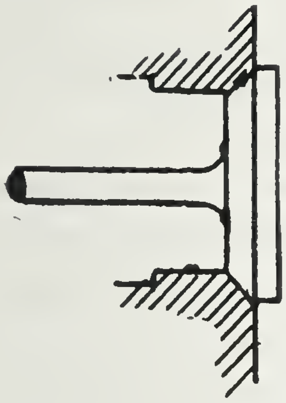

FIG 12

OUTLET VALVES.—All outlet valves seem to be somewhat similar in construction, being principally of the "poppet" type, and are operated by means of a cam placed on the slow moving shaft, the details of the arrangement depending on the peculiarities of the engine. Fig. 13 shows the Otto arrangement. In both the cases of the inlet and outlet valve they are arranged to be open for one full stroke and should then close rapidly if of the "poppet" type, in order that the valve may fit properly in its seat. Poppet valves have now been adopted in the Otto engine as made in Philadelphia.

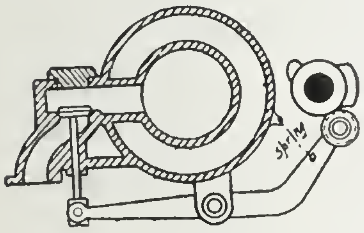

FIG. 13

GOVERNORS.—Governors are sometimes arranged to operate the exhaust, and sometimes to operate the inlet valves.

A means of governing the outlet valve is by sliding the cam along the shaft so that it does not come into contact with the lever connected to the valve when the speed is too great. The cam may be fastened to the shaft by means of a feather, which will make the cam revolve and will still allow motion endwise. One type of governor for the inlet valve has already been explained. In case of the latter (poppet) type of valve, the governor often merely controls the end of a small lever attached to the operating rod for the valve, the lever operating a valve on the main gas pipe as in the case of the governor in Fig. 11. When the speed of the engine is too great the lever is lifted clear of the valve and no gas is admitted.

It may at first be thought that the governing of the outlet valve would have no effect, but when the pressure of exhaust is noticed it will be readily understood that if the cylinder be full of gas at high pressure there will be no opportunity of getting fresh gas in for ignition unless this gas is released.

IGNITERS.—There are three kinds of igniters, one of which has already been mentioned, and which consists of a tube in which the gas is allowed to burn, the flame being made to communicate at certain definite times with the explosive gas in the cylinder.

Another type similar to this in some respects is the hot tube igniter which seems to be quite frequently used. A tube of platinum or some such substance is placed in such a position that the explosive charge may communicate with the outside of it, but the tube having an end in it the charge cannot get inside. On the inside of the tube a gas flame burns continually and keeps the tube at white heat. The tube is kept away from the explosive mixture until the time for the explosion comes, when the valve allows the two to communicate and the charge is fired. This igniter has some advantages in that there is nothing about it to leak or get out of order, but it is found that the excessive heat soon destroys the tubes and makes the scheme somewhat expensive.

Another kind is the electric igniter, which consists of some method of making a spark in the explosive gas at the required time of ignition. This method seems to be an excellent one, as it does away with all the hot tubes in the other igniters, all that is required being a fairly large battery, several large gravity cells being often used and an induction or spark coil. The igniter may be operated by a crank on the slow moving shaft to which is fastened a rod, the end of which has a lineal motion and may be so adjusted as to bring the points into contact as desired.

COOLING WATER.—The water for the water-jacket is always forced in at the bottom of the jacket, and allowed to run off at the top after it has been considerably heated in cooling the cylinder. The supply may be either taken from some convenient source, as the water works service, or a circulating tank may be provided, in which case the bottom of the tank should be level with the bottom of the jacket, the same water being used over and over. Very little water is required, and a half-inch pipe seems to be sufficient for the supply in a small engine.

WORKING FLUIDS.—The working fluids are various. Illuminating gas seems to have the preference on account of its convenience, although it is the most expensive.

A quality of gas known as "water gas," made by blowing steam over red hot coal or coke, is also used and is found to be very good.

Carburetted air is used in gasoline engines. The gas is produced by drawing air over the surface of gasoline, having a specific gravity of about 0.65 to 0.67. Air treated in this way has an equal heating power to coal gas, and the great objection to the use of gasoline seems to be in the danger of explosion in the storage tank.

A gas quite generally used in self-contained gas engine plants is made by the Dowson process. A jet of steam from a small boiler is blown through an injector, where it is mixed with air, and the mixture is then passed over red hot coke or anthracite coal. The gas is then led through scrubbers into a storage tank. The calorific value of this gas is about one-fourth that of coal gas.

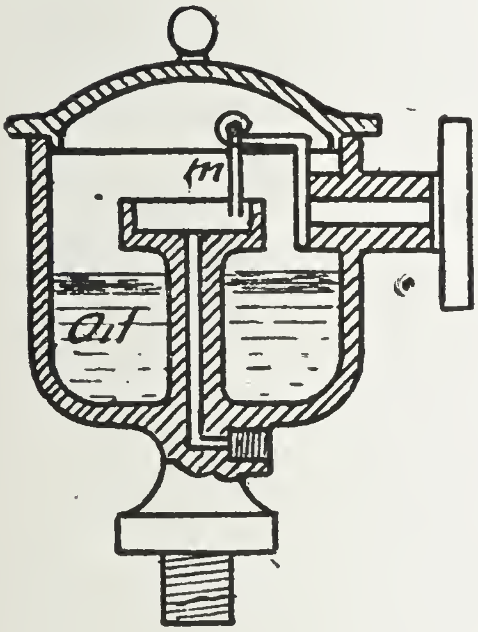

FIG 14

Oiling.—All gas engine cylinders must be well oiled, and various methods are adopted to accomplish this. The apparatus used in the Otto engine is shown in the Fig. 14. The wheel *i* is driven by the engine and is supported on a shaft having on its inner end a crank on which hangs loosely a pin, *m*. As *i* revolves the end of the pin dips into the oil in the large vessel, then rises up to the inner vessel, where the oil is wiped off and runs down inside the tube to the piston. In many cases ordinary lubricators are used, the only requirement being that the supply of oil must be positive.

Results Obtained in Practice.—Results of tests made on the gas engine show that it compares favorably with other prime movers.

In a series of tests made by the Society of Arts, in 1888, on several engines, the consumption of coal gas was about 20 cubic feet per I.H.P. per hour, as shown in the following tests: In an Atkinson engine in which the expansive stroke was longer than the compressive stroke, the consumption was but 19.2 cubic feet. A trial made on the Crossley-Otto engine at the same time showed 20.8 cubic feet per I.H.P. and 24.1 cubic feet per B.H.P., showing a mechanical efficiency of 86 per cent. The speed of the engine was 160 revolutions per minute, and it developed 17.12 I.H.P., or 14.74 B.H.P. The amount of cooling water used in the jacket was 713 lbs. per hour, which was raised 71°.8F. in temperature. Thus of the total heat developed 22 per cent. was converted into useful work, 43 per cent. given up to the cooling water, and 35 per cent. went off in the exhaust. The equation to the expansion curve of the diagram was $pv^{1.435}$=constant, and that of the compression curve $pv^{1.38}$= constant approximately. The temperature of the exhaust was 2,130°F., gas after compression was 1,060°F., and the maximum was 3,440°F. all absolute.

A simplex engine tested in 1889 showed a consumption of 21.55 cubic feet per H.P. per hour of town gas (607 heat units per cubic foot), and 88.03 cubic feet of Dowson gas (150 heat units), the jacket water used in the latter case being over 8 per cent. more than in the former.

REPORT OF A TEST OF A SEVEN HORSE-POWER ENGINE.*—Working capacity of the cylinder .2594 cubic feet, clearance volume .1796 cubic feet.

Temperature of gas supplied	62°.2F.
“ “ “ exhaust	774°.3F.
“ “ entering water	50°.4F.
“ “ exit water	89°.2F.
Pressure of gas in inch of water	3.06
Revolutions per minute (average)	161.6
Explosions missed per minute	6.8
Mean effective pressure, pds. per sq. in	59
Horse power indicated	4.94
Work per explosion, foot pounds	2,204
Explosions per minute	74
Gas used per I.H.P. per hour, cubic feet	23.4

Heat Units.	Per cent. of heat received.
Transformed into work	22.84
Taken by jacket water	49.94
“ exhaust	27.22

COMPOSITION OF GAS.

	By volume.	By weight.
CO_2	0.50%	1.923%
C_2H_4	4.32	10.797
O	1.00	2.279
CO	5.33	15.419
CH_4	27.18	38.042
H	51.57	9.021
N	9.06	22.273

On the tests above quoted the gas engine converts about 20% of the energy of the fuel into work, while the steam engine converts only about 15%, and more often 10%, of the energy of the fuel into work.

In ordinary working of engines using Dowson gas the consumption of anthracite coal is about 1.3 lbs. per I.H.P. per hour, and Messrs. Crossley, in England, guarantee on 300 H.P. engines using this same gas but 1 lb. coal or $1\frac{1}{3}$ lb. of coke per I.H.P. per hour, which is considerably superior to the steam engine.

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* Journal Franklin Institute, Feb., 1890.

Gasoline engines are on a par with steam engines using 6 pounds of coal per H.P. per hour, for the gasoline engine consumes about $\frac{1}{10}$ gallon gasoline per H.P. per hour, which, at 8 cents per gallon, brings the cost down to $\frac{8}{10}$ cent, corresponding to a consumption of 6 pounds coal when coal is at $3.00 per ton.

This shows a very decided advantage for the gas engine, more especially when it is remembered that if the gasoline be employed no attendance is required, and there is no loss either when starting or stopping the engine.

On the other hand, although gas engines developing 320 H.P. have been constructed, yet they do not seem to be in general use, and the steam engine is used wherever considerable power is required.

Although the gas engine is, comparatively, very efficient, yet, as has been pointed out previously in this paper, very great losses result from the high temperature of the exhausted gases and from the amount of heat carried off by the water-jacket, and there is still room for improvement in these respects.

Another point requiring attention is the devising of a means of causing explosions to occur at each stroke instead of every fourth stroke. The present method requires very heavy fly-wheels and excessively large cylinders, which of course contribute considerably to the loss in the jacket.

CONCRETE AS MADE ON THE TRENT CANAL DURING THE SEASON OF 1896.

By H. F. Greenwood, M. Can. Soc. Civil Engineers.

Before beginning the paper proper, it might be well to mention when and how concrete has been utilized on the great canal works of Canada. These will be taken somewhat in the order in which they were built.

In the first enlargement of the Welland Canal, the foundations of the locks were generally made of concrete and timber. Concrete was used very extensively in foundations, when the Lachine Canal was enlarged, and also in the locks along the Ottawa River. The canals along the St. Lawrence River, between the head of the Gallops Rapids and the foot of the Cornwall Canal, have concrete and timber foundations in all their locks, some of these bottoms containing as much as 2,000 cubic yards of concrete. Then the Sault Ste. Marie lock advanced concrete a step by showing its utility as a material for backing walls. It was also used in foundations and culverts at the same place. But the Soulanges Canal is really the pioneer as regards concrete for walls. Here the entrance piers (about 1,100 feet in length) at the head of the canal are made of crib-work as high as the level of low water mark. After these cribs had properly settled, a wall of concrete eight or nine feet high was built upon them. Besides being very substantial, this has proven a success and looks quite as well as masonry. When the work on this canal was let, alternative bids were asked for masonry throughout, and for concrete walls faced and coped with cut stone. Which of these kinds of work will be used the writer cannot say.

This brings us to the Trent Canal structures which were built wholly of concrete, no stone-work being used at all. The concrete works constructed during the season of 1896 were on the Peterborough-Lakefield Division, of which the writer has charge. This division consists of sections Nos. 1 and 2, with a firm of contractors for each section.

The work on section No. 1 consisted of one lock, and the concrete in connection with two dams which were in the course of construction across the Otonabee River, for the purpose of raising it to the proper level for navigation.

The concrete works on section No. 2 consisted of the following:—Pivot piers and abutments for two swing bridges, abutments for one high level bridge, these latter abutments being 33 feet above the bottom of the canal, concrete in connection with a pipe culvert which conducts a creek under the canal, and concrete walls in two water-tight embankments.

The writer proposes to give, as briefly as possible, a description of the methods used and the precautions taken in constructing some of these works.

The specifications state that the contractors shall supply at their own cost, all plant, labor, moulds and materials necessary for the satisfactory execution and completion of the works, with the exception of the cement, which is supplied by the government.

Sand and Gravel.—Extreme care was used in selecting the materials for concrete. The sand and gravel for section No. 1 were hauled in the winter, and were not at all difficult to find, as the conical and hog's-back hills in the vicinity are formed of these materials. Yet to find them free from clay, and to get coarse, sharp and well-proportioned sand caused some delay, The contractors sub-let this to the surrounding farmers and local men with teams at so much per cubic yard delivered on the works. Samples were brought to the engineer's office by these people, and it was some weeks before the proper kind of sand was obtained. The well-intentioned sub-contractor thought that what he dug out should go into his sleigh-box and none be wasted. So it was necessary to put an inspector at the pit to see that earthy matter, very fine sand and clayey gravel were all rejected, as it would be much more difficult to detect these after the material had been hauled to the works.

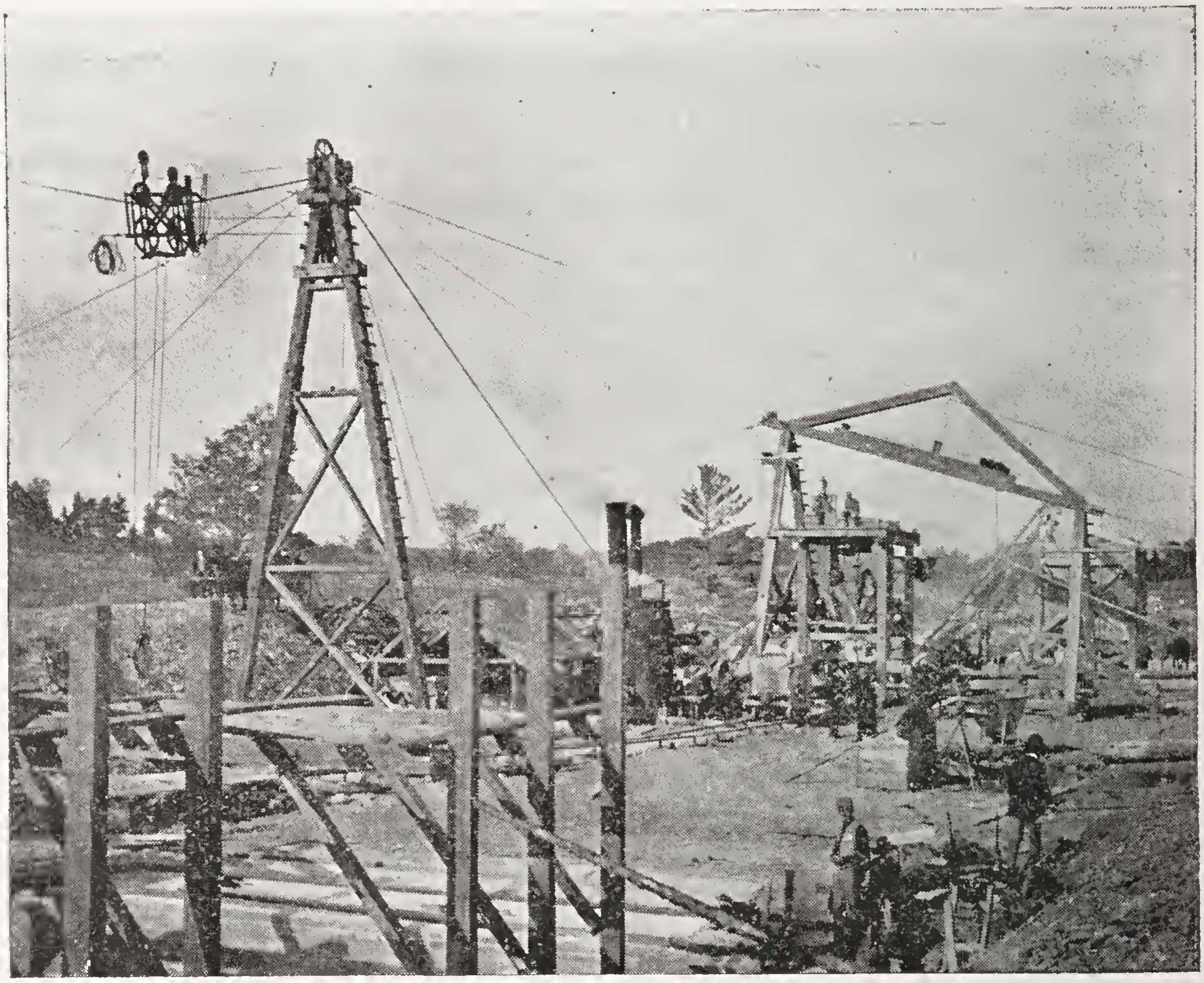
On section No. 2 the sand and gravel were obtained in a similar way; and, as the work progressed, delivered by dump-wagons at the side of the mixing platforms. These self-dumping wagons were of advantage to the contractors for this purpose, as they carried large loads and saved delay in emptying. Hauling the material as it was required saved moving it a second time; but unless the contractor had his own teams and wagons he could not be sure of a constant supply.

The following table is the result of sifting samples from two different grits :—

	Residue on 400.	R. on 900.	R. on 2,500.	Passed 2,500.
1st sample..........	19%	51%	22%	7%
2nd sample..........	8	42	38	12

Both of these have given good results.

CEMENT.—The cement for the season was let by contract, to be delivered in cars at the railway siding nearest the work, where it was handed over to the contractor. One of our Canadian firms, the manufacturers of the Star brand, secured the contract, but they were not able to keep the works supplied and also satisfy the demand from outside customers. The consequence was that after a time they supplied us with the Condor and Josson brands of Belgian cement. All cements were subjected to the following tests :—Color : the cement to



CONCRETE MIXER

be of a uniform quality and of a light gray tint, after being made into thin cakes and exposed to the air, and in no case must it show yellowish blotches. Weight: the specific gravity to be not less than 3.1. Tensile strength, per square inch of section, to be as follows: neat cement after three days 250 ℔s., seven days 400 ℔s., twenty-eight days 550 ℔s. Fineness: All cement to be ground of such a fineness that 90% of it passes through a sieve of 10,000 holes to the square inch. Soundness: this was determined by Faijas apparatus. All pats when subjected to a moist heat of 110° Fahr. and warm water, to show no signs of blowing, for 24 hours after the tests were begun. All the above mentioned brands gave good satisfaction, but the Star brand was found to be more finely ground than the other cements. Unlike the other brands, it was supplied in "jute" sacks which were found by the contractors to be more easily handled when using the mixing machine; but the writer considers that there is more waste, as a certain amount remains in the sacks when emptying them. Six samples of cement were taken from each car as soon as it arrived in Peterborough, and these had to pass the following tests, viz., sifting, specific gravity, and blowing, before the car could be sent to the contractor's siding, where it remained until the three-day test for tensile strength had been made. If this proved up to standard, the car-load could be transferred to the cement-shed erected by the contractor close to the railway siding.

Broken Stone.—The specifications called for this to be free from earthy matter and to pass through a two-inch ring. The crusher used on each section was well adapted for the work it had to do. On section No. 1 they used a "Blake" jaw crusher to break the selected stone from the excavated limestone strata. On section No. 2 a "Gates" crusher of coffee-mill type was used, and there the stone were principally hard-heads from the fields, or boulders from the excavation. The jaw crusher on section No. 1 run by steam, crushed about 150 cubic yards per day, while with the machine on section No. 2 electricity was used and a cubic yard of broken stone was obtained in 3½ minutes.

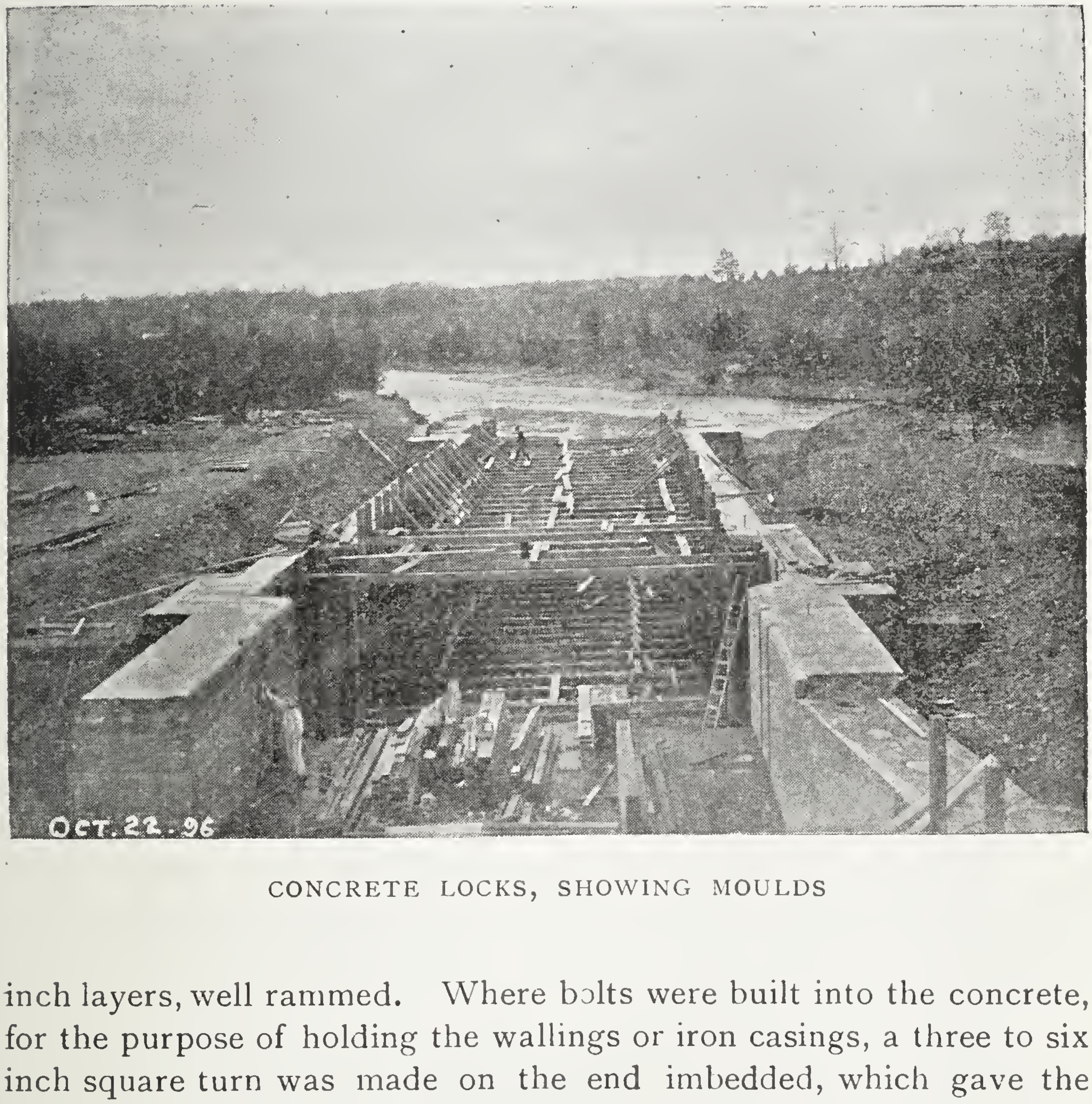
Moulds.—The moulds for shaping the face of the lock walls were made by placing braced rectangular frames every five feet apart, and arranged so as to extend across that part of the lock for which they were intended. When they were in place, three-inch planed plank with half-inch lap joints were spiked to the vertical pieces and thus formed the face of the wall. Moulds of unplaned boards, made like very long doors and placed end to end on edge, formed the back of the wall. These moulds, the same height as the proposed steps, were braced from the face of the excavation.

The moulds for the concrete, placed in front of the timber dams, were made in a similar way. In order to avoid sharp edges, mouldings with radii of from two to four inches were placed at all exposed angles less than 120 degrees.

For the bridges, the water-tight embankments, etc., the moulds were formed of scantling and plank placed in the same way as the moulds for the face walls of the lock, but were held in position by braces from the surface of the ground. Nearly all the face walls of bridges were built to a batter; whereas those of the locks were built plumb. In the high level bridge, the moulds at the back were held in position by iron rods passing from front to rear of the wall.

Methods of Making Concrete.—On section No. 1 the concrete for the lock was mixed by machinery and that for the face of the dams by hand.

The mixing machine consisted of a cubical sheet-iron box revolving on its diagonal axis about six feet above the ground. This box was held up by a frame-work which also supported a platform above the box, and let into this platform was a hopper for receiving the materials. In the rear of the mixer was the crusher with a carrier leading from it into a large box hoisted on posts, to receive the broken stone. The stone was let out of this box, by a small sliding door, into a car that held one cubic yard of stone. The stone was then taken by car and dumped into a large oak box, holding 1¼ yards, placed near the mixer. The cement which had been deposited on a platform close at hand was dumped in upon the stone. Then the sand and gravel, brought in from the sand pile by another car, was dumped in last and about filled the box. The box was then hoisted and the contents dumped into the hopper. A barrel on the platform of the hopper was kept filled with water by a force pump at the river bank, and from this barrel a graduated tub was filled to the required height. When everything was ready the door of the cubical box was opened, and, when the slide door of the hopper was shot back, the tub of water was poured in as the materials were falling through into the mixer, which was then closed and revolved. It was found necessary to strike the mixer with mallets to keep the materials from sticking to the sides. After about sixteen or seventeen revolutions, the mixer was stopped and the concrete dropped into a box on a flat car beneath. It was then conveyed to the cableway, hoisted and run into the lock where, for the foundation, it was dumped, spread out in a layer of eight or ten inches and well rammed. For the walls the face was formed of mortar of proportion two to one, and two to five inches in width, as the case required, placed against the face mould, and this mortar was backed up by concrete in eight to ten-inch layers, well rammed. Where bolts were built into the concrete, for the purpose of holding the wallings or iron casings, a three to six inch square turn was made on the end imbedded, which gave the bolts an L-shaped appearance; the other end of these bolts had a nut and washer on them. This arrangement was continued throughout, and a three-inch layer of mortar properly smoothed over formed the coping. By this process a cubic yard was manufactured every five minutes. The best ten hours' mixing was 140 cubic yards.



CONCRETE LOCKS, SHOWING MOULDS

The concrete on section No. 2 was all mixed by hand, and here the proper proportions of cement, sand and gravel were thoroughly mixed together on the platform and spread out. Clean water was now added and the mass well worked with hoes. Broken stone was then spread over this and the whole turned over twice. It was then put into barrows, wheeled and dumped into the work, where the layers were well rammed, and the face of the wall treated as on section No. 1. The concrete along the face of the dams on section No. 1 was made and put in place in a way similar to that on section No. 2, except where it had to be placed in three or four feet of water, and then the following apparatus was used, viz.: a galvanized sheet-iron tube about one foot in diameter, and long enough to stand, when vertical, about two feet above the water. The upper end of the pipe was funnel-shaped. When the concrete was mixed it was shovelled into the tube, and, when this was full, it was raised about one foot and moved about. This allowed the concrete to slip down and more was added. Thus the concrete was put in without becoming saturated, as after the tube was once filled its contents did not come into contact with the water until it had left the bottom of the tube when it was in the place intended in the wall. After a few days an examination showed that this concrete was quite satisfactory.

On section No. 1 a portion of the stone was much finer than the size called for, and consequently less gravel was required. After several trials it was found that the following proportions were most suitable, viz.: One part cement, two parts sand, two and one quarter gravel and seven of broken stone. On section No. 2 there was a less proportion of finely broken stone, and hence it will be seen that more gravel had to be used. The parts here taken were: cement, 1; sand, 2; gravel, 3½, and broken stone, 7.

REMOVAL OF MOULDS.—The moulds for the smaller walls were not removed until after five or six days, and those of the higher, and, consequently, heavier walls, were kept on for several weeks.

After the removal of these moulds, the walls present a very fair appearance, although there were occasional small projections, where the plank had drawn apart and mortar had worked in; but these were easily removed with the edge of the trowel. The outlines of the plank were left visible and gave one the impression of masonry courses. Where there were pine knots in the plank an impression of these knots was left on the wall, and these spots were found not to have hardened like the rest of the surface. However, a wash of water and cement, with which the faces of nearly all the walls were treated, remedied this.

ADVANTAGES.—About 11,000 cubic yards of concrete works were built during the season, and in the same classes of work the cost was not over two-thirds that of masonry. Its advantages are cheapness, expediency, the utilization of the ordinary laborer instead of the skilled mason and stone-cutter ; and, besides these, the stone is more easily found. The use of this class of stone has a tendency to beautify the surrounding country, as the farmer is paid to remove those objectionable stone-piles one so often sees dotted over his farm.

HYDRAULIC MINING IN BRITISH COLUMBIA.

AN ADDRESS DELIVERED BEFORE THE SOCIETY BY

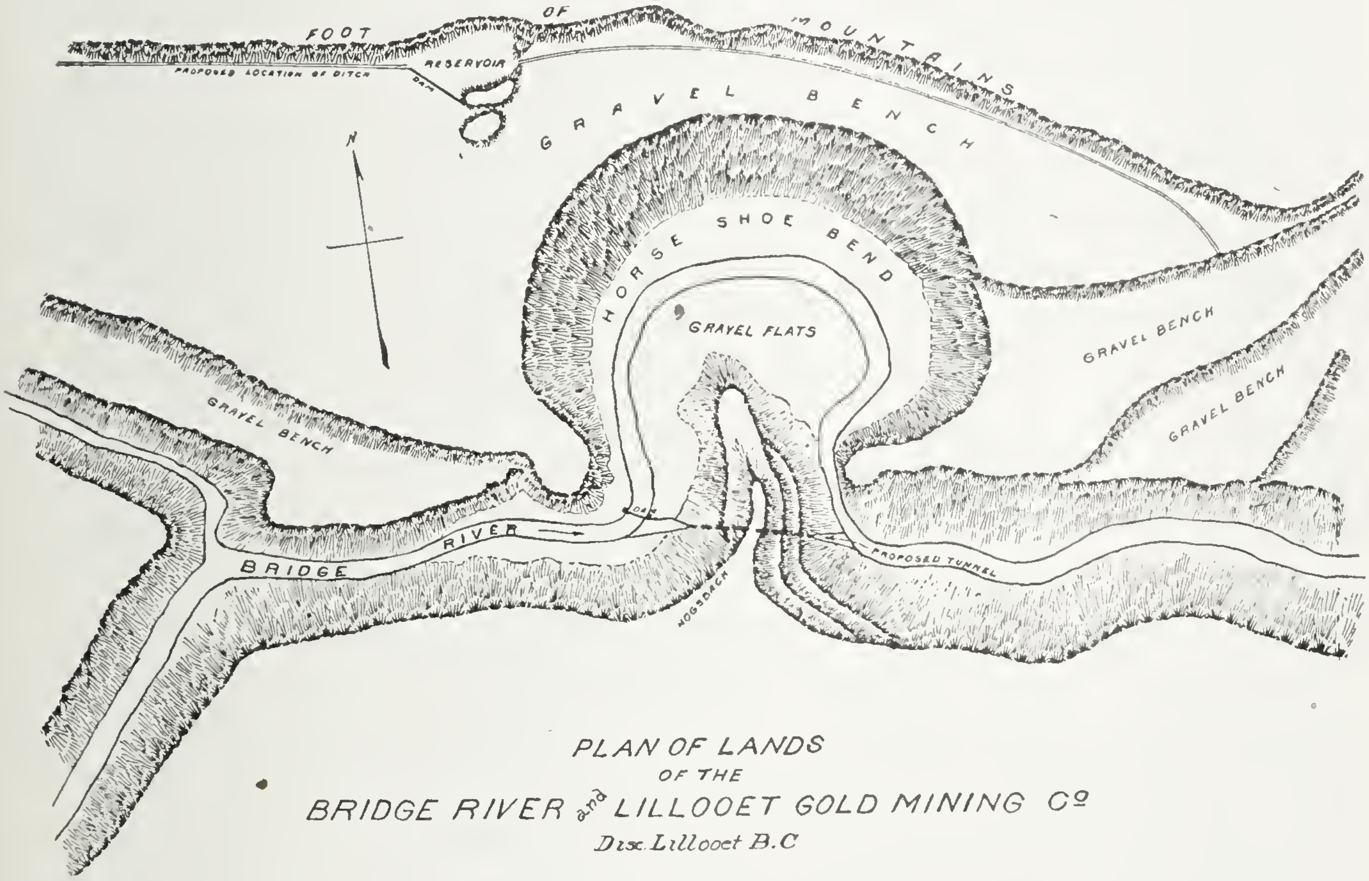
J. W. TYRRELL C.E. *(Tor. Univ.)*, M. CAN. SOC. C.E.

MR. PRESIDENT AND GENTLEMEN :

I am afraid there may be some disappointment in expecting a paper from me to-day, as I have not been able to find time to prepare one. However, I have here a plan of a placer mining proposition in British Columbia, upon which I have been, and am still working, and shall be very pleased indeed to give as full an explanation of the proposition as I can, and shall be glad to answer any questions which may be asked in connection with it.

As you will see by the title on the map, the name of the property is the Bridge River and Lillooet Gold Mine of the District of Lillooet, British Columbia. The claim or rather claims (for there are a number of them consolidated) are situated on the Bridge River, seventeen miles above its junction with the Fraser, to which it is tributary. The central feature of the claims is a large horse-shoe bend in the river, which itself flows in a deep gorge through banks of gravel about 450 feet in height. At the upper end of the horse-shoe the river strikes a protruding point of rock, which diverts its course and causes it to flow around to the north, thence easterly, then southerly through a narrow gorge between two rocky bluffs, and thence again to the eastward. It is expected that the bed of this horse-shoe bend, which is a broad gravel flat, will prove the richest part of the mine. The Bridge River is well known to be one of the richest gold-bearing streams in British Columbia. Through the narrow canyons which exist on the upper portion of the river it flows at the rate of five or six miles an hour; but when it strikes this protruding point of rock, which is about 350 feet in height, and which is commonly known as the "Hog's Back," the river is suddenly diverted and its current is very greatly reduced, from about five or six miles an hour to three or three and a quarter; so that, its velocity being checked, it will naturally deposit in the bed of the stream whatever gold it carries. It cannot do otherwise. This accounts for the rich gold deposits which have been found in the horse-shoe bend, as much as $140 to the cubic yard having been taken from portions of it.

Bed rock has not been reached at all as yet. The richest deposits of gold in these placer mines are usually at bed rock below the gravel; so that it is expected something very rich will be found at the bottom. Sufficient prospecting has, however, been done on the property to prove beyond any question that it is rich in gold, but it has not yet been prospected thoroughly. They now propose to sink a number of shafts and prospect holes so as to be able to determine with comparative accuracy the value of the whole property. This it is quite possible to do in the case of these placer mines. For instance, along the face of the banks of the river, which are about 450 feet in height, one can cut channels from top to bottom and ascertain the exact percentage of gold at various elevations down the face of the bank. You can readily see by taking a section from north to south through the horseshoe along those banks in a couple of places, and again, along the face of those steep banks from east to west, that you will get cross-



PLAN OF LANDS
OF THE
BRIDGE RIVER and LILLOOET GOLD MINING Co
Dis. Lillooet B.C

sections which should give a fair average, and in that way a close estimate can be readily formed of the value of the whole property. If they determine to go into the matter more thoroughly, as some companies do whose claims are less favorably situated, they can sink shafts from top to bottom of the beds; but, of course, such shafts would be much more expensive than open channels in the face of the banks.

The whole property, I may say, lies in a deep valley between mountains which attain heights of five and six thousand feet on either side. The line marked "foot of mountains" is the foot of a range of mountains about six thousand feet in height. The southern boundary of the map approximately indicates the position of the foot of the mountains to the south of the Bridge River.

One of the most essential elements to success in hydraulic gold mining is an abundant water supply; and in this we are most fortunately situated. We are able to intercept the north fork of the Bridge River at a point about three miles west of the Company's claim, and thus bring a whole river down over their property to wherever it may be required, and have a head of 450 feet for working the lower beds of the property. As you probably understand, these gravel beds are all to be washed by jets of water brought down through this open canal and thence through open pipes, and discharged through what are called giants into the face of the banks; the gravel in this way is washed out from the banks and thence conducted into sluice boxes, through which the gravel is passed, the gold extracted and the refuse gravel carried away to the most convenient dumping place. In cases where ample dumping ground is not conveniently available, a cable carrier or elevating machinery is necessary in order to dispose of the great quantity of refuse gravel. In this case I do not think anything of the kind will be necessary. This mining location is most favorably situated in respect to the disposal of the refuse gravel; the channel of the river, as you see, is about 450 feet in depth. By commencing operations at the lower end of the property and working west or up stream, they will be forming a dumping ground as they advance with the work; as they wash the gravel from one place it will be transferred to a position a few hundred feet to the east of its original place, until the upper end is reached. There is probably enough gravel in these beds to furnish the company with all they can do for the next forty years, and that even with a very large supply of water. The

Company has already secured 5,000 miner's inches of water, which is more than is being used by any mining company in British Columbia at the present time.

In order to dry the rich auriferous gravel bed in the bend of the river, it is proposed to construct a tunnel through the point of rock called the " Hog's Back," then dam the river and turn the stream through the tunnel. It is hoped in this way to be able, without much difficulty, to work the gravel to the bed rock, however deep that may be. It is said to be from thirty to forty feet below the bed of the river.

The total area of the claims of the Company amounts to 719 acres, and the total number of cubic yards of gravel amounts to about 366,000,000.

I may say that right at the grass roots on top of these high benches, which are 450 feet above the river bed, by prospecting in a number of places, an average of ten cents per cubic yard has already been found, and in one place, at the base of the gravel bank, as much as $140 to the cubic yard. As to getting down to bed rock, we have not done that as yet.

The property is situated about eighty miles from the railway; Ashcroft is the nearest station. For sixty miles there is a good stage road kept up by the Government of British Columbia ; the remaining twenty miles is pack trail.

It is estimated that about $78,000 will be sufficient to equip the mine ready for hydraulic operations.

The course of the proposed water channel will be along the foot of the mountains to the north of the property. It is estimated that the water can be brought from a point three miles distant from the property, to where it may be required, for from twelve to fifteen thousand dollars. As compared with some of the other placer mines of British Columbia, this is a very small sum. The famous Cariboo Mine had to bring the bulk of its water supply for a distance of eighteen miles ; and even after going to the great expense of bringing it that distance through extensive fluming and ditching, the supply was found to be insufficient, and other ditches had to be made, at great cost.

At this property there are probably 15,000 miners' inches available, although we are only bringing in 5,000 inches, that being considered ample. If necessary, the whole north fork of the Bridge River is available for use in working the mine.

The property is situated immediately to the west of the lands of the Indian Reserve, which are known to be highly auriferous as well, but on account of being held by the Indians they are at present not available for mining purposes. The lines of etching on the map represent different steps in the benches, each one being from fifty to one hundred feet lower than the upper one, the elevation of the highest bench being about 450 feet above the river bed in the horseshoe.

There is very little rock found on the property, only at three or four points; one at Gibson's Bluff, on the west side of the horse-shoe, again in the centre of the horse-shoe, where it is proposed to build the tunnel, and on the east side of the horse-shoe a bluff also occurs; but the remainder of the property is all gravel. It has evidently been of ancient river deposit, as one can clearly see from an elevation of three or four thousand feet. I took the trouble to climb up through the snow, although it was up to my waist, and, being without snow-shoes, I had to simply wallow through it to get up. I reached an elevation of about 3,000 feet on the south side of the property, and from there got an excellent view of the whole claim; and it was quite clear that the ancient bed of the north fork of the Bridge River had been along the foot of the mountains to the north of the claims. This was particularly shown by a great slide of rock existing immediately to the west of the property. There had, in by-gone ages, been an enormous slide which had probably thrown the north fork of the river out of its original channel and caused it to flow in its present one. The confluence of the two streams had in former years, I believe, been somewhere in the vicinity of the horse-shoe itself. The former existence of the river to the north of its present position, along the foot of the mountains, would account for the existence of the great auriferous gravel beds.

I might say that the whole property is beautifully timbered. I never saw more lovely forests than occur right here on these high bench lands; they are as level as the floor, and the whole property is really a lovely park. The trees are all fir and pine, and there is no fallen timber at all. There is any quantity of timber for the construction of flumes, dams, tunnel-lining, or any other purpose. There is no building stone in the district, the rock found being of a soft nature.

I do not know that there is much more I can say, though I will be very pleased to endeavor to answer any questions that any gentleman present may feel disposed to ask.

Mr. Carter—What is the scale of the drawing?

Mr. Tyrrell—Two hundred feet to the inch. The total length of the claims from east to west is about two miles.

Mr. Yeates—How is it they are able to get that much frontage? Is that sub-divided?

Mr. Tyrrell—Yes. There are about ten leaseholds consolidated into one. The property was originally taken up in the names of these ten parties, and it was transferred or assigned by them to the Bridge River and Lillooet Gold Mining Company. The frontage limit of one claim is 1,500 feet, with an area of eighty acres, 1,500 feet along the river and going back sufficiently far to make up eighty acres. In some cases the mountains are so close that we could not get eighty acres in a claim, and they had to be reduced to whatever they might happen to be.

Mr. Duff—What is the quantity contained in the miner's inch?

Mr. Tyrrell—That is a question that I had occasion to look up a good deal, for this reason: that a miner's inch varies in almost every country, and almost with every mining company. The miner's inch is really not a thoroughly established unit. In British Columbia, however, it is defined by statute, so that it is a fixed quantity there, and it is this: The quantity of water that will pass through half an opening one inch vertical by two inches horizontal, cut through an inch board having a head of seven inches above the centre of the opening.

In some places it is the quantity of water that will pass through an opening one inch square, with a head of six inches, and in some places the thickness of the board is one, two and three inches, so that that of course affects the discharge a good deal.

Mr. Bain—What will be found per cubic yard to pay for working?

Mr. Tyrrell—About two cents a cubic yard has been found in many cases to pay for working; three cents will pay very well, and anything over that proportionately greater. It depends a good deal on the character of the gravel. If the gravel is found to be cemented, as it is in some mines, three cents would not pay at all. In the famous Horse Fly Hydraulic Mine, of the Cariboo District, the gravel is cemented a good deal, and they are now putting in stamp mills to crush it; so that probably twenty-five cents a yard would only about pay them in that case. The engineer of that company claims that he can crush the gravel at the cost of twenty cents per cubic yard.

In this mine there has been no cemented gravel found, and the three cents a cubic yard would pay handsomely. Two cents would pay working expenses.

Mr. Piper—What is the weight of a cubic yard of gravel?

Mr. Tyrrell—I think it runs just about a ton.

Mr. Mitchell—With the exception of the Hog's Back, did you find any rock on the river?

Mr. Tyrrell—Further up the north fork there are rocky bluffs. There is some along the river bank, but, excepting at the points I have mentioned, no rock shows on this property.

Mr. Mitchell—The indications would be then that there would be no auriferous gravel found to the west of the horse-shoe, where you say the slide of rock occurred?

Mr. Tyrrell—Gold-bearing gravel is found further up the stream than the horse-shoe. I have not been up there myself, but I have been informed by prospectors and free miners who have been working up there that rich gravel beds do exist further up.

Mr. Mitchell—But not on this claim?

Mr. Tyrrell—The whole of the bed of the stream is gold-bearing. Chinamen were working on a portion of the river bed east of the horse-shoe at the time I visited the mine, and they had to be ejected. They were making handsome dividends.

Mr. Wilkinson—How is the gold found deposited in the gravel? In the free state?

Mr. Tyrrell—In the free state in small nuggets about the size of a finger-nail—thin, flaky nuggets. No doubt some fine gold does exist, but what they have obtained so far in their prospecting has altogether been of the coarse description.

Mr. McMillan—Does the size of the gravel increase as you go up the river bed in this case? Does it start off small and increase in size as you go up?

Mr. Tyrrell—No; I don't know that there is any marked difference in the nature of the gravel. It appeared to be pretty uniform all the way up the banks, except in the river bed. The bottom of the river itself is formed of boulders, the finer gravel having washed down and worked its way between the boulders. The bed of the river itself is essentially a mass of boulders, and in that way forms a natural sluice-box to catch whatever gold the river carries. Some of the boulders would probably have to be handled with derricks.

Mr. Webster—Is all the mining of the Cariboo hydraulic ?

Mr. Tyrrell—A great portion of it.

Mr. Webster—They do not find out where all this gold comes from ?

Mr. Tyrrell—No ; that is a question to which men are devoting all their energies. I was rather anxious to find the place where it all came from, when I was out there. (Applause.)

Mr. Stull—About how much water is necessary for the treating of the gravel ?

Mr. Tyrrell—One miner's inch will treat all the way from two to ten cubic yards of gravel in twenty-four hours, depending on the character of the gravel, the grade of the sluice-boxes and the magnitude of the work generally ; but an average is about three and a half cubic yards of gravel for one miner's inch per day of twenty-four hours. In the Cariboo Mine at the present time, according to the statement of their engineer, Mr. Hobson, they claim to be handling ten cubic yards of gravel per day, with one miner's inch, by the use of the most modern hydraulic machinery.

Mr. Stull—What pressure do you get in bringing the water down ?

Mr. Tyrrell—We have a head of four hundred and fifty feet.

FOUNDATION FOR A TWENTY-ONE STORY BUILDING.

By T. Kennard Thomson, C. E. *(Tor. Univ.)*
M. Am. Soc. C. E.

The most novel foundation for a high building ever constructed in New York, or at least the one containing the most unique features, is that for the new 21-story building for the Commercial Cable Company, south of and adjacent to the New York Stock Exchange. The new building has a frontage on Broad Street of 45 feet, and about 56 feet on New Street. The distance between the two streets is nearly 160 feet, covering the sites of four old buildings.

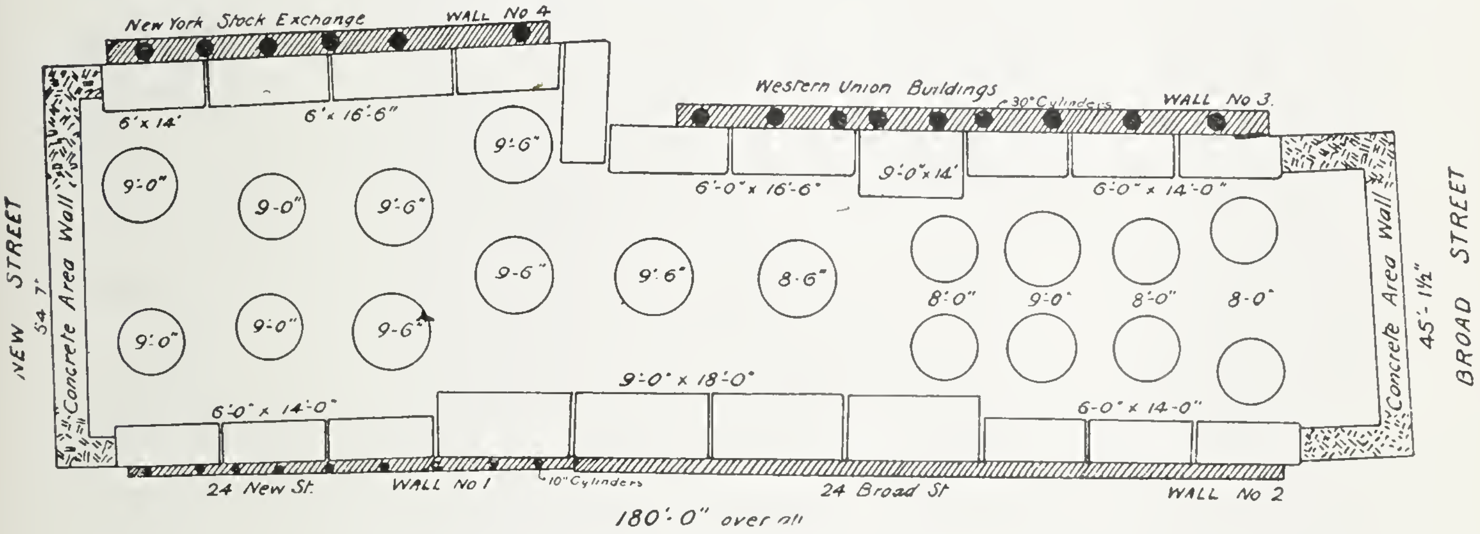
The essential features which made these foundations so entirely different from anything heretofore attempted, was the requirement that there should be a cellar and a sub-cellar below the curb, which necessitated an excavation over the entire lot to a depth of 20 feet below the level of the ground water. The water in the ground here flows freely at an elevation several feet above mean high water in the bay.

The foundation contractors had to give heavy bonds as a guarantee that they would make the cellar water tight, the methods of securing this result being left to their judgment, and they probably paid more for engineering assistants than any contractor ever paid for a job of this magnitude.

The contract was signed during the last week of January, 1896, and work was at once started. Three of the old buildings had been removed, while the fourth, a small, but shaky brick structure, next to the Stock Exchange, was not vacated until the first of May. It was decided to sink a series of rectangular caissons along each side of the lot, having a space of about six inches between them, which spaces were to be filled in by some means not then determined upon. There were 21 of these rectangular caissons which carried the side walls and columns, the smallest being 6 by 14 feet, and the largest 9 by 18 feet. They all had an air chamber 7 feet high, and about 27 feet of steel cofferdam on top. The ends were also enclosed as described later on, making the whole lot water tight. In addition, there were 18 cylindrical caissons inside of the lot, to carry the intermediate columns.

The first thing done was to get up rough plans of these caissons, to enable the bridge companies to make their bids, and while they were preparing their estimates, the plans were elaborated, so that the steel could be ordered at once, and before the steel could be rolled and received from the mills, the detail plans were ready for the shop.

As some of these caissons weighed from 14 to 15 tons when shipped, a powerful travelling derrick was required to move them from the trucks to their position for sinking. This traveller was a stout wood frame affair, about 15 feet wide, 25 feet long, and 20 feet high, having a mast and boom at each of the four corners, and a vertical steam boiler for each boom, which was capable of lifting at least 20,000 pounds. A heavy timber trestle, strong enough to carry a railroad train, with two rails 13 feet apart, was designed to carry this derrick from one end of the building site to the other, and as the New Street end was about seven feet higher than the other, the trestle was made a few feet higher than New Street, allowing the trucks to drive on at this end, and giving plenty of room, about 10 feet, below for working.



PLAN OF LOT, SHOWING DISTRIBUTION OF CAISSONS

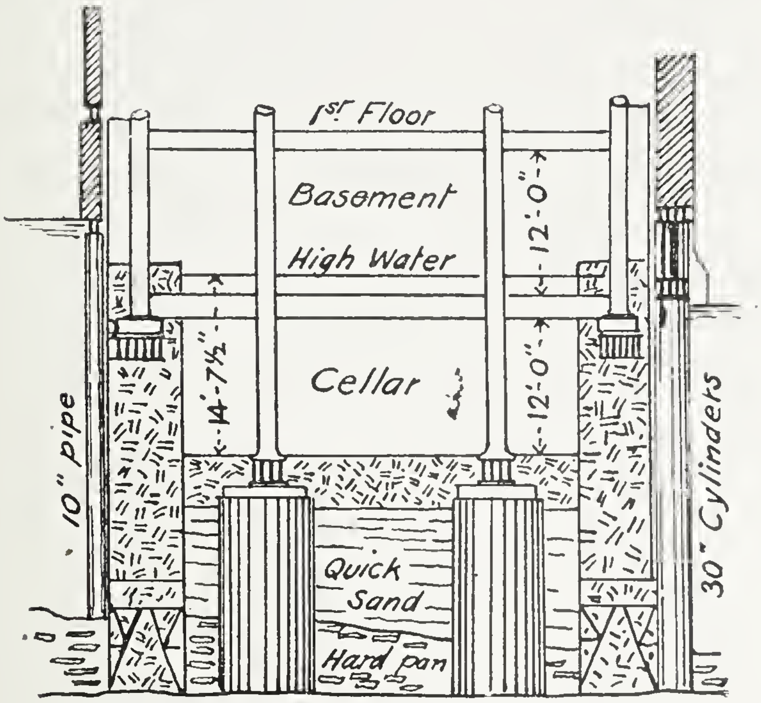
The first actual work done on the ground was to drive 68 piles, from 30 to 36 feet long, to carry this temporary trestle. These piles were driven to hard pan, which was as far as they would go. Sixteen piles, one-third the length of these, were driven to support the two air compressors for the caissons.

The lot had previously been excavated to the level of the adjoining cellar floors, and in many places below the foundations of the adjoining walls of three buildings, so that it was possible to shove a foot rule or pencil under these walls. As the two buildings on the south had restaurants in the cellar, the floors of which were directly on the quicksand, it was not surprising that the glasses rattled, and that there were frequent protests from the scared tenants and their patrons whenever the pile driving was going on. Although the contractors had authority to keep on driving, they preferred to lose a little money for the sake of causing as little annoyance as possible, therefore they suspended work from 11 a.m. to 2 p.m., lunch time, and worked on a public holiday.

The old building next to the Stock Exchange and wall No. 1 were very dilapidated and shaky, the bricks being set in lime mortar, which was very little better than dry powder. Wall No. 1 had masonry cellar walls, which were even worse than the brick work. Wall No. 2 was a party wall, six stories high, with nothing to hold it in place but the wooden floor joists, so that it was to be expected that the driving of the temporary piles would give these buildings a severe shaking. They were very carefully watched. The building may have settled a little ; in fact, the janitor claimed that the doors would not shut, but as this building was to be pulled down anyway, it did not matter. No further damage was done, but all were relieved when the pile driving was finished.

In the meantime, it was decided that it was absolutely necessary to underpin wall No. 1, and Mr. Breuchaud, of the firm of Arthur McMullen & Co., invented an ingenious method of doing this permanently, and without taking up valuable space by clumsy wooden shores, as is usually done, which would have to be moved several times.

He cut a horizontal hole in the wall about 4 feet long and 10 feet above the ground. Into this he placed two 12-inch eye-beams, and then made a vertical cut in the wall about two feet wide from the eye-beams to the bottom. Into this recess he placed 5 foot sections of 10 inch gas pipe, and by means of a 60-ton jack between the top of this 10-inch pipe and the bottom of the eye-beams, and the aid of a water-jet, the 10-inch pipe was forced down 5 feet, when another section was added, and so on, until 34 feet of pipe had been used, until the bottom was resting on hard pan ; the jack was then removed, and the pipe filled with concrete, and new brick work built over it in place of the poor stone wall. Nine of these pipes were used under the 56 feet of wall.



SECTION, SHOWING UNDERPINNING IN ADJOINING WALLS

Wall No. 2, although well built, barring lack of foundation, was so top heavy, not being properly bonded to any other wall, that was decided to tear it down and build a new one. This was done, the side of the house was boarded and tar-papered until the first six caissons had been sunk, when a good concrete foundation was put in 6 or 7 feet below the old foundation, giving a solid bearing for the new brick wall.

The only adjacent wall then accessible, which was apparently able to stand up by itself, was wall No. 3, part of the Western Union Building, a heavy 8-story brick structure, resting on three rows of piles, which where supposed to have been driven to rock, so the first caisson was placed against this wall, and the sinking was started ; but before it had penetrated ten feet, the principal or outside row of piles under wall No. 3 was found to be encroaching on the ground of new building, and had to be cut off to allow the caisson to sink. It was then discovered that some of these piles were only 8 feet long, instead of 35 feet, and that they all stopped short from 10 to 20 feet above rock. It was evident that it would be unsafe to proceed with the caisson work until this building had also been underpinned ; therefore, the air was let off, the air chamber and the space was filled with water, to prevent drawing any material from under the Western Union building, and it was over one month before the work of sinking could be started again.

The method of underpinning this building was similar to that adopted for wall No. 1, but inasmuch as the weight was so much greater, the cylinders were made 28 inches inside diameter, instead of 10 inches, and after they had been forced down to hard pan by two 60-ton jacks, the jacks were removed, and an air lock put in their place, which permitted pumping the water out and sending a man down to excavate the hard pan to solid rock. The cylinders were finally filled with concrete, properly capped, and built into the wall; but before this had been accomplished wall No. 2 had been pulled down, the first six caissons stretched along the wall as fast as they arrived, and sunk two at a time.

These caissons are strong steel boxes, having no bottom, but a roof or deck, seven feet above the bottom or cutting edge. The sides extend two feet above this deck, and had horizontal angles to connect to similar angles in the cofferdam, the connection being made by bolts every four inches. Rope gaskets soaked in white lead were placed between the angles, to prevent leaks. The sides and ends of the cofferdams were shipped separately, and bolted on in 5-foot vertical sections, with rope gaskets in the vertical as well as horizontal joints. As a rule, there were five sections, five feet high, bolted on as the caisson sank, making 34 feet from the cutting edge to the top of the cofferdam, which was, as near as possible, one foot above the water line.

To the deck of all caissons were bolted two three-foot shafts, with rope gaskets, one shaft for removing the material, and one for the use of the men. These shafts were added at the same time as the cofferdams were, and the space between the shafting and the sides of the cofferdams was packed with well rammed concrete until there was from 15 to 20 feet of concrete above the roof or deck, the aim being to stop the concrete just below where the iron base for the columns was expected to come, the rest of the cellar walls being built after the columns were in place.

The cofferdams were so designed that four feet of each end could be taken out to make the concrete cellar walls continuous. Both excavating and man shafts had of course air locks, the air being supplied through a hole in the man shaft. As the excavating lock was very heavy, weighing about 5 tons, and would be too high in the air if all the shafting were put on before sinking started, only about ten feet of shafting was placed under this lock until the caisson had sunk as far as it could, when the air lock was removed, and more shafting added; generally it was necessary to remove the excavating lock once only, but in some cases it had to be done several times, and when this was being done, a wooden door was placed under the roof, and puttied with clay, the pressure of the air in the working chamber preventing the heavy door from falling.

The pressure of the air was, of course, regulated by the depth of water outside, and was kept slightly greater than the calculated amount. If the pressure was not high enough, the water would rush into the caisson, and if too high, the air would blow out, and suddenly decrease the pressure, and allow the water to enter through the "blow out." The maximum pressure required on this work was from 15 to 20 pounds per square inch, which is not supposed to be enough to hurt a man in good health, with no organic trouble. The friction on the sides was very great, running from 150 to 450 pounds per square foot of exposed surface of the sides of the caissons and cofferdams, and when this was added to the upward pressure exerted by the compressed air, the sum was greater than the weight of the steel and concrete, so pig iron was piled up on top of the concrete sometimes to the extent of a hundred tons.

There were generally from four to six men working in the air chamber, in eight hour shifts, filling the buckets, which held nearly one-half a cubic yard, and were pulled out and emptied by the travelling derrick. As soon as the cutting edge was well bedded in the hard pan, the sinking stopped, and the excavation was carried on below the cutting edge to rock; the rock was quickly cleaned off, and concrete dropped through the lock, rapidly shovelled and well rammed in place.

It is very difficult to make concrete hold water, but as it was essential that no water should find its way under the cutting edge, up through the caisson into the cellar, a thin layer of mortar was laid on the concrete, about six inches above the cutting edge, and on this good stout canvas was spread, with edges lapping several inches, and covered with a few inches of mortar, after which the concrete was continued to within four inches of the deck, the remaining space being rammed full of mortar. Only Portland cement was used on this job. It can be readily imagined what a difficult thing it is to fill up the deck all around, and gradually back out through a three foot shaft. The shafts were finally filled as high as the outside concrete, and the upper sections removed with the air locks to the next caisson. The rectangular caissons having all been sunk by this means, with the spaces between them ranging from 2 to 12 inches, it was necessary to devise some means of closing these spaces, in order to have a water tight wall before digging the cellar. Stock ramming was tried, and found very successful. This consisted of driving down a three-inch pipe to the hard pan, dropping pellets of clay into it, and then forcing the clay out at the bottom by means of a pile driver acting on a long rod or piston ; after a certain amount of clay had been forced through, the pipe was drawn up a little, and more clay sent down, and so on, making a compressed clay wall from hard pan to the surface. In some cases the clay was forced horizontally along the caisson ten feet away from the pipe. The pipes were generally put down in two positions between the caissons, and held the water out even better than had been hoped. Part of the clay was afterwards removed to make place for a permanent brick filling.

The caissons were sunk on an average 35 feet to rock ; on top of the rock lay from 2 to 14 feet of hard pan, while nearly all the rest of the material up to the surface is quicksand. It might be stated here that nearly all of the lower part of New York rests on quicksand, which very few architects seem to be aware of.

Having two water-tight walls along the sides completed, the next thing was to produce these walls to the vault or area line under the streets, and to close the ends, as this portion does not carry any of the weight of the building, and all that was required being a temporary water wall down to the hard pan, and a permanent water-tight wall and retaining wall down to the sub-cellar floor, it was decided to drive a patented sheet piling to answer the first purpose, and build a concrete wall against this for the second purpose. These sheet piles were made of three pieces of plank, each 2½ x 12 inches, and about 40 feet long, well bolted together, making a pile 7½ x 12 inches. The centre plank forms a three-inch groove on one edge, and consequently a three inch tongue on the other.

As the piles were driven very carefully so as to keep the tongue in the groove of the next one all the way down, they held back the water and material until the concrete retaining or area walls were finished. Of course these sheet piles were strongly braced with heavy timbers, as the cellar was being excavated.

While all this was going on, the 18 cylindrical caissons in the interior of the lot were also being sunk. These were 8 feet, 9 feet, and

9 feet 6 in. in diameter, there being six of each size. They were shipped in two sections; the bottom, or permanent section, containing a $6\frac{1}{2}$ foot air chamber, was 16 feet high, and the top, or temporary section, 18 feet high. There was not room to place any concrete over the deck before sinking, as the interior columns are below the cellar floor. The space over the deck was filled with water, and a timber frame carrying four "crabs" or winches was placed on top, and the wire ropes passed through sheaves attached to the frame, and others attached to eye-beams on the ground, which was held down by pig iron, etc. By placing several men at each crab, the 16-foot section was pulled down in about 12 hours, or as fast as the material could be dug out and removed from the caisson. If the caisson sank faster than the material was removed, as sometimes happens, the men would not have sufficient working room in air chamber. By working quickly, the water did not cause enough trouble to require using compressed air for the first section, but by the time the top or temporary section had been added, the water had risen enough to necessitate using air for second section. The air chamber was cleaned out and filled with concrete the same as the rectangular caissons. The contractors were obliged to sink the cylinders before excavating the cellar or closing the ends, in order to allow the erection of the columns and girders, the weight of which prevented any danger of the new cellar walls being forced in by the overloaded foundations of the adjoining buildings, which was a decided advantage, as well as saving in time for the frame working.

After the cellar had been dug out, and four feet of concrete placed in the floor, the top 18 feet of the circular cofferdams was cut in two vertically, and the horizontal bolts taken out at the bottom, leaving no obstruction above the floor except the column and girders.

It might be well to state here that while this is by no means a typical case of New York foundations, it should be. Unfortunately, there are very few foundations so carefully put in. One reason is that engineers very seldom have control, although the features are chiefly engineering. In many cases competent engineers are not employed, or if consulted, are not heeded. Of course there are exceptions, but they are few and far between. This applies to the whole building, as well as the foundations.

It seems a pity that in a place like lower New York, with rock so comparatively near the surface, and a thick layer of treacherous quicksand overlying it, that "sky scrapers" should be allowed whose foundations do not go to rock.

ON SNOWSHOES FROM THE BARREN LANDS.*

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On the morning of the 6th of November, after a stay of seventeen days at Fort Churchill, our party was ready to set out for the south. We had secured the services of one dog-team with driver, and an Indian guide to accompany us to York Factory, the next Hudson Bay Company's post, about one hundred and seventy miles farther south, but about two hundred miles by the circuitous autumn route.

Our team consisted of six Eskimo dogs, and they were attached tandem fashion to a sled twelve feet long and a foot and a half wide. This sled was of the regular Eskimo type, with runners formed of sticks hewn down to the dimensions of about two inches by six inches, curved up slightly and rounded in front. The platform of the sled was formed of slats laid across the runners, to which they were securely lashed by sealskin thongs ; and, lastly, the shoeing of this peculiar conveyance consisted of mud, put on in a soft state, and, when properly formed, was allowed to freeze, after which it was glazed over with a coating of ice.

Upon this sled was loaded our provisions, blankets, etc., all securely lashed on within a canvas wrapper. Our guide, whose name was Jimmie Westasecot, was a large, fine-looking Cree Indian of about middle age, who bore the distinction of being the most famous hunter and traveller in all the country. Our party now consisted of ten ; my brother and myself being warmly dressed in the deerskin garb of the Eskimo, whilst the rest of the party wore the white blanket suits of the traders, and, with the exception of poor little Michel, whose feet, having been frozen during the former part of our journey, were still entirely too sore to allow him to walk, each man was provided with a pair of snowshoes.

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*An account of Mr. Tyrrell's explorations in the Barren Lands with map of the route will be found in the proceedings of the Ontario Land Surveyors' Association, 1896.

Thus provision was made for the transport of all necessary supplies; but we were obliged to provide for Michel also. Here a fortunate opportunity was presented. Mr. Matherson, who had a boat load of supplies lying on the coast, rather more than half-way down to York, had determined to accompany us with other teams as far as his cache, and offered to take him that far, and we expected by that time our load would be sufficiently light to take him ourselves. Mr. Lofthouse, the Missionary, also had goods at the boat, and added one more team to the expedition, making a total of fifteen men and five teams.

After taking farewell of our kind friends we marched from the Fort in single file, forming into a long serpentine train, winding our way to the southward across the broad frozen Churchill river, which, during the severe frosts of a few days previous, had become sufficiently frozen to allow us to cross in safety.

At the outset of the march, though our party had greatly improved physically during our stay at Churchill, we were still far from being strong, but we were anxious to push homeward as early as possible. Because of our physical condition it was thought best not to make forced marches at the outset, and the wisdom of this resolve was clearly proven before our first day's tramp was ended. On the afternoon of our first day's march my knee gave out, and within an hour or so every step caused me excruciating pain, and it was with the greatest effort that I managed to hobble along after the train until evening. We travelled about twenty-one miles during the day, on an easterly course, across open plains and snow-covered lakes, little timber being met with until we reached the " Eastern Woods," where it was decided to camp. Upon the open plains we had found the snow hard and in good condition for travelling, so that our teams had trotted along with their heavy loads with little difficulty, and but few administrations of the ponderous lash. The snowshoe travel was also comparatively easy for those whose legs were sound; but the moment we entered the woods the snow was light and soft, and travelling became much more difficult, making it necessary to send one ahead to break the way.

The snowshoes used by Jimmie, our guide, were about five feet long and eighteen inches wide, whereas those used by the rest of our party varied from three to three and a half feet in length and from ten to twelve inches in breadth. Though we purchased the shoes from the Hudson Bay Company at Churchill, they were made by the Chipewyan Indians. Their shoes are not made symmetrically, but are constructed with great bulges on their outer sides, and are formed of two pieces of wood, tied together at both ends, and held apart in the middle by cross-bars, whilst the toes of the shoes are turned up with a sharp curve.

Having reached the shelter of the "Eastern Woods," and concluded our first day's march, a camping place was chosen.

The drivers of the teams at once proceeded to unharness the dogs, make beds for them of spruce boughs, and give them their daily meal of seal blubber or fish.

The other members of the party busied themselves by clearing away the snow, cutting down brush and fire wood, and building the camp. Our camp consisted simply of a wind-break of brush built three or four feet high of a crescent or "U" shape, and in such a position as to best afford shelter from the cutting wind. The snow was then cleared from this space and several inches of spruce boughs strewn in its place, and a good fire kindled in front.

Next thing was to prepare for supper. Our appetites, to be sure, were all ready, so bacon and biscuits were hauled out, whilst frying pans and tea-kettles were produced, and placed with their contents upon the fire. Fresh water had been found by cutting through the ice of a creek close by, and so nothing was lacking. Our simple meal was then heartily enjoyed, after which preparations were made for the night. Socks, duffles and moccasins—wet with perspiration from the day's march—were hung up before the fire to dry; robes and blankets were brought from the sleds and spread about the camp, and upon them our tired party soon assembled to enjoy a rest and smoke beside the fire before turning in for the night. My brother and I, who shared the same blankets, chose a middle position in the camp, our own men occupying the space to our left, whilst Mr. Matherson and his men occupied the space to our right. The night, though cold, was beautifully calm and clear, so that when the big dry sticks of wood were thrown from time to time upon the fire, showers of sparks ascended until they found hiding places among the dark branches of the overhanging spruce trees.

Camp fire stories and gossip were indulged in for an hour or so, and then about nine o'clock, several big logs were again thrown upon the fire, and each man rolled himself up in his blanket and lay down to sleep. There was little sleep for me, however, because of my knee, which gave me great pain during the night.

Upon the next morning camp was called at five o'clock, and under the still star-lit sky all hands rolled out into the keen, frosty morning air. A fire was soon kindled, breakfast prepared and partaken of, sleds loaded, teams harnessed, snow-shoes examined and put in order, and at the first streak of dawn our tramp resumed.

It was yet dark in the woods, and to most of us there was no more indication of a trail in one place than in another; but our veteran guide, "Jimmie," who possessed all the sagacity of the ideal red man, led the way, and what the rest of us had to do was merely to follow his tracks. Soon we merged from the Eastern Woods, and, getting into a more open country, we turned our course towards the south, crossing broad plains dotted here and there by stunted scattered trees and ice-covered ponds.

As we travelled my leg caused me great pain, so that it became impossible for me to keep up with the train. I hobbled along as well as I could for a time; but finding that I was seriously retarding the progress of our march, arrangements were made to give me a lift for a while upon one of the sleds.

Peter and Louis were also becoming lame from the effect of their snowshoes, but were not seriously crippled. (For the benefit of any who may not be aware of the fact, I will explain that there are various forms of lameness commonly produced by the prolonged use of snowshoes. In thus travelling certain leg muscles which are only accustomed to perform light service are brought into vigorous use, and are very liable at first to become strained and cause much annoyance).

During our second day from Churchill a band of twenty or thirty deer were seen. Some of us were in no mood or condition to hunt; but Jimmie, our guide, and Mr. Matherson, went off in pursuit of the band, while our train pushed on. Several times during the afternoon we crossed the tracks of both deer and hunters, but when we came upon the big tracks of our guide we saw the first signs of success. He had evidently wounded a deer, and was giving him a hot chase, for the Indian strides were right upon those of a cariboo, and to one side of the trail spatters of blood could be seen on the snow. Toward evening our train came up with Mr. Matherson and Jim, who had had a long but fruitless run after the deer, but nothing could be seen of the guide. He had evidently entered the race to win, and had resolved to run his game to the ground; for, some time after camp had been made for the night in a thin patch of woods, Jimmie walked in with a haunch of venison on his shoulder. He had wounded his deer early in the afternoon, but had been obliged to run him many miles before he could again come up with him. He had slain his victim a considerable distance from camp, and lest the carcase should be devoured by wolves in the night, a team was harnessed and Jimmie himself and one other man started off for the meat, which some hours later during the night they brought into camp. As we had had very little fresh meat for some time past, supper of venison steak was very much appreciated.

During the day's march numerous wolf and several Polar bear tracks had been crossed, but the cariboo were the only animals that were seen.

The next, our third day's tramp, was a short one, not in actual miles travelled by some of the party, but in distance made upon our course. It was, however, a big day's sport, for, during the day, no less than eight deer were shot. Unfortunately for my brother and myself, we were not able to take part in the chase, for by this time, though I was beginning to recover, my brother was as badly crippled as I had been, and for a time had to be hauled on a sled.

At about the close of the day, a little deer which Mr. Matherson had been following, and at which he had been practising for some time with my brother's rifle, stood and looked at him with innocent amazement, at a distance of about 300 yards from our train. Probably the cause of Mr. Matherson's wild shooting was the cross-wind which was blowing strongly at the time, but, however, he gave up in disgust and returned the rifle to my brother, asking him to try a shot. My brother said it was useless for him to try, as the deer had now run still farther away, and he himself had only one leg to stand on. However, dropping upon his knee, he fired one shot, and down dropped the deer, much to the astonishment of Mr. Matherson.

Several of the best haunches of venison secured during the day were loaded upon the sleds, but it was not thought wise to over-load the teams by trying to carry too much. The bulk of the meat was cached where it was killed, to be picked up by the Company's team upon their return trip and taken to Churchill, where it was much needed.

Our third camp was made in a strip of wood upon the bank of Salmon Creek, and to our Indians is doubtless memorable as being the place at which they had the big feed, for it took three suppers to satisfy them that night. With my brother and myself, the hours of darkness had ceased to give us repose, for our knees were so painful we could not sleep, but only turned restlessly from side to side, until the return of dawn. Happily for us all, the weather had continued to be fair, and not extremely cold since the commencement of our journey, and this was particularly fortunate on account of poor Michel, who would doubtless have suffered, had he been obliged to ride upon a sled all day during extreme weather. As it was, we were able to keep him fairly comfortable—bundled up in deer skin robes and blankets.

Upon the fourth day of our journey, meeting with no deer, we made about twenty-seven miles—a good march, considering the loads of our teams and the condition of our party. This brought us to the banks of Owl River, a stream two or three hundred yards in width, and situated in a straight line, about midway between York and Churchill. Here, at half past five o'clock, being then about dark, we camped.

At dawn the next morning we were again marching southward, with the expectation of that day reaching Stony River, where William Westasecot, a brother of our guide, was encamped, and the place at which our parties were to separate.

Three more deer were shot during the day, making a total of twelve so far for the trip—most of them being the victims of the Indian guide. About four o'clock in the afternoon, we arrived at Stony River, but there was no Indian camp to be seen, and for a time we saw no signs of the proximity of any human being. We turned down the river, and ere long came upon the tracks of a solitary hunter. These Jimmie knew to be the tracks of his brother, and by following them a mile or two into a dense evergreen wood, we came upon the camp. It was a solitary tepee situated in the heart of a snow-clad thicket of spruce trees and scrub, so dense that a bird could scarcely fly through it.

The Indian lodge or tepee was built of poles placed closely together, and arranged in the shape of a cone. The cracks between the poles were chinked tightly with moss, with which the tepee was then covered, excepting a foot or so at the top, where a hole was left for a chimney. An opening, made in the wall as a doorway, was closed by a heavy curtain of deerskin; and, as we lifted it, in the centre of the lodge, upon a square mud-covered hearth raised a few inches above the surrounding clay floor, a smouldering wood fire burned, from which the circling smoke ascended and found its way through the chimney, whilst the old Indian rose from his seat and extended a welcome to enter. Deerskin cushions were offered, and as we seated ourselves more wood was piled on the fire.

William, the Indian, was a much older man than his brother, our guide, for his long flowing locks were already whitened with age, though he still appeared strong and athletic. His squaw and two sons completed his household, and to each one we handed a piece of tobacco. Pipes were then lighted and information sought and obtained of the Indian. We found that he had only seen and killed one deer for some weeks past, and was now almost out of food, and entirely out of ammunition. We supplied him with the latter, and told him where within a day's travel he might supply himself with the former.

We learned from him that the great Nelson River, which we expected to reach within two or three days, was still quite open ; but he told us where, some miles up the river, we would find a large boat in which we might cross. It was arranged also that Eli, William's elder son should accompany us to York and assist by hauling a flat sled.

Whilst my brother and I and our guide were thus interviewing the Indian, our own camp was prepared a short distance away, and having completed plans for the morning we bade farewell to the red man, and losing the track by which we had come, had to struggle back through the thicket.

The next morning, being the 11th of November, the separation of our parties was arranged. The route of Mr. Matherson's party henceforth lay off to the eastward, whilst our path still led to the southward, toward the banks of the Nelson River. A place was prepared upon our own dog sled for crippled Michel, our team of six dogs was harnessed, and the flat sleds, including one for Eli, were then loaded with all that the dogs were unable to haul. Our supplies had by this time diminished to the extent of about two hundred and fifty pounds so that even with the additional weight of a man, our loads were lighter than at the outset of the journey.

Loads being thus readjusted, and our feet being harnessed to snow-shoes, we bade farewell to our friends from the Fort, as well as to those of the forest, and made a new start on our journey.

The weather had now become very mild, making the snow soft and even wet in some places. This made travelling very heavy for the team, causing the ice glazing to melt from the sled, and the mud shoeing to wear and drag heavily upon the track. My brother and I still suffered much pain from our knees, but with considerable difficulty we managed to keep up with the rest of the party, and after making a small day's march, camped for the night in a spruce wood on the bank of a small stream called by the Indians, White Bear Creek. On the following morning camp was called early. The weather had turned slightly colder during the night, making the prospects for travel more favorable. We started down stream upon the ice of the creek, and then across country through a thick spruce woods, to Duck Creek, where we found a second Indian camp. It was occupied by two Cree Indians and their families.

From one of these Indians we were able to purchase an additional dog, and the price asked was a new dress for one of the squaws ; but as we had no dress goods with us, the best we could offer was that the dress should be ordered at the Hudson Bay Company's store at York, and delivered at the first opportunity. After several pipes of tobacco had been smoked, the offer was accepted, and with seven dogs in our team our journey was resumed —the creek being followed till it led us out to the low, dreary coast at the mouth of the Nelson. Here, having left the woods several miles behind, we were exposed to the full sweep of a penetrating south-west wind, and although on the coast of Hudson's Bay no water was yet to be seen. We are accustomed to thinking of a *coast* as being a definite narrow shore line, but to the inhabitants of the Hudson's Bay region, the word conveys a different meaning. There the coast is a great mud and boulder flat several miles in width, always wet, and twice during the day flooded by the tide. At this time of the year the mud flats were covered by rough broken ice and drifted snow, but above high tide mark the surface of the country was level and the walking good. For several hours we tramped southward down the coast with the cutting wind blowing in our faces. Towards noon we began to look longingly for some place of shelter, where we might make a fire to warm ourselves and prepare some lunch, but we pushed on until the afternoon was well advanced without finding a shrub or stick to afford shelter or fuel. A consultation was held, and the result was that our course was altered and shaped for the nearest woods several miles inland. A rapid tramp followed, and when the woods were again reached, the shelter and refreshments were both heartily enjoyed

The great advantage of travelling on the open plain is that there the snow is driven hard and hence the walking is much better than in the woods. Nevertheless, when the weather is rough, as it was on this occasion, the heavy walking is preferable to travelling in the open country in the teeth of a storm.

For the remainder of the day we tramped southward within the shelter of the woods, and, at about the time of sunset, made camp on the south bank of the stream known as Sam's Creek, in a lovely snow-ladened evergreen bush—an ideal Canadian winter woodland picture. From this beautiful, but chilling scene our tramp was continued the next morning at daylight. The low shore of the Nelson was again reached and followed, until about noon a decided change in the character of the land was observed. A boulder clay bank commenced to make its appearance, and this as we advanced rapidly reached an elevation of twenty-five or thirty feet; and, as we proceeded farther up the river, became higher and higher and more thickly wooded. The change was a great relief from the level, dreary, treeless coast.

We were now well within the mouth of the great Nelson River, and could already, through the rising steam from the water, dimly see the dark outline of the opposite shore.

Considerable ice was found to be coming down the river, and on this account we could not help feeling some anxiety as to crossing; but we were within a few miles of the boat of which we had been informed, and it seemed probable that we might yet cross the stream before nightfall. At half-past three o'clock in the afternoon we found the boat drawn up in the mouth of Heart Creek, where William, the old Indian, had told us it was. It was a large, heavily-built sail boat, capable of carrying our whole outfit in one load, but, unfortunately, the keel was deeply imbedded in the sand and there securely frozen. The only way to free it was to chop it out, and to this task as many hands were set as could find room to work. We only managed, however, to get the boat loosened as the shades of night fell about us. We were then obliged to seek a place to camp. The river bank had here become very high and precipitous, but a short distance up the gorge we discovered a scattered grove of evergreens, and a camp was made beneath them.

During the night the wind, which had been blowing for two days past from the south-west, gave place to a gale from the north-west. Moreover this unwelcome guest did not come alone, but brought with it a driving snow-storm, which lasted all night. The gale shrieked through the trees, and threatened havock with our fire and blankets, and by daylight the snow which accompanied it had almost buried our party.

Such was our condition on the morning of the 14th, and such the first chilling view that greeted us; but we soon pulled ourselves out from the snow-drifts, and, after a good deal of searching, found sufficient dry wood to kindle a fire, with which a scanty breakfast was prepared. I say a "scanty breakfast," for this being our ninth day from Churchill, our supply of provisions was about exhausted; but we were now only one day's march from York, and so lack of provisions troubled us but little. After breakfast, notwithstanding the roughness of the weather, all hands at once proceeded to the boat, and by a united effort just managed to drag it out to the edge of the shore ice; but there, the tide being low, there was no water to float it, so we had to await the flood tide, which would not be up till about noon. Meanwhile, the boat was loaded where it rested upon the sand, and at twelve o'clock, being lifted by the water, a canvas was hoisted, and through a dense fog which rose from the river, we sailed up the shore in order to reach a narrow part of the river, and avoid broad shoals, which existed off the shore opposite to us. Having sailed about three miles up the river, along the shore, to the vicinity of Flamboro Head, our course was altered, and we steered into the fog for the south shore, about two miles distant. It was intensely cold, but, as there was a good breeze, our craft sped swiftly away on her course. Some floating ice was met with, but successfully passed, and for a time it seemed as if our crossing would soon be effected; but suddenly there loomed out of the mist, right ahead, a dense field of ice, broken and rafted and hurrying down with the current.

By putting our helm hard to starboard, and quickly dropping our canvas, we barely managed to keep clear of the ice, but what was now to be done? The south shore was still hidden by the dense fog, and nothing could be seen in that direction but the adjacent field of ice. On the north shore the dark outline of Flamboro Head could still be seen through the mist, and it was resolved thence to beat our retreat. We were, however, unable to sail against the wind, but taking to the oars, after a prolonged struggle we managed with great difficulty in a half-frozen condition to regain the place from which we had started.

Once more on land the camp was made, and a fire kindled, at which to thaw our stiffened limbs, and await our opportunity to cross the river. The fog continued during the remainder of the day, preventing us from making a second attempt, and so we camped for the night.

By the next morning the fog had cleared away, revealing a dismal sight. On the south side, the river was frozen over, and the ice firmly set for a mile or more from shore, but the channel of open water north of this was running full of heavy ice, thus making our crossing more perilous, and as it was impossible to effect a crossing on foot, we were obliged to await a change in the condition of the river. Not the least unpleasant circumstance in connection with this waiting was that our provisions were now exhausted.

However, the men were sent out to hunt, and returned in the evening with nine ptarmigan, with which a good "bouillion" was made for supper. Besides this, Eli, the Indian boy, gave us some comforting information as to the existence of a fish cache of his father's not far distant. With this consolation and the resolve to send for the fish in the morning, we rolled up in our blankets and were soon dreaming of better times at home.

The next morning saw no change in the condition of the river, so two men and the dogs were sent after William's fish cache and other four of the men went off hunting, whilst the rest of the party remained in camp, collected wood, and kept the fire burning.

We had nothing to eat until evening, when the sledding party returned with a little bag and can of pounded dried fish, two or three gallons of seal oil, and some seal blubber for the dogs, all of which, though not exactly luxurious, we were exceedingly glad to receive. Later, two of the hunters returned with several ptarmigan and one or two rabbits, and last of all, some time after dark, the remaining two—Jim and our noble guide—walked into camp carrying the carcass of a deer. We had now sufficient provisions for several days, and they were divided equally with the party.

Without narrating in detail the incidents of the following days, it will be sufficient to state that for ten long days, this weary wait on the bleak, cold banks of the Nelson was continued. From time to time the men were sent out to hunt, but, except as above mentioned, were obliged to return without success.

On the morning of the 19th the guide and Jim, provided with rifles, blankets, axes and snowshoes, started off up the river, determined to find deer if there were any in the neighborhood, and also to investigate the possibilities of crossing the river further up.

Four days of bitterly cold weather passed, the thermometer varying from 12 to 25 below zero, and then empty-handed, they returned. Food had again become scarce with us, and a fox which had been trapped was eagerly devoured.

On the evening of the 22nd, though the mercury indicated 22 below zero, the channel of the river above us was observed to be less thickly blocked with ice than where we were encamped, so it was resolved, if possible, to haul the boat a mile or two farther up stream and there to launch and measure our strength with the floe.

No time was lost, but all hands, excepting Michel, who was still unable to walk, engaged in the work. The boat, which had been kept chopped free from the ice, was launched, and by means of a long line we managed to tow it about half a mile up the shore, but then the ice became so dense that to prevent the boat from being crushed, it was necessary to haul it out on the shore. About a mile farther up was the point we desired to reach, so we were obliged to haul our boat along the shore It was all we could manage, but by about nightfall we had gained the object in view. Then, by the light of the moon, we proceeded to move camp to the boat, so that in the morning, if it were possible to cross the river, we might be ready.

Next morning, the weather being bitterly cold, and a fog rising from the water, the prospects for boating were not the most pleasant, but we were resolved to effect a crossing if possible.

We towed the boat half a mile still farther up the river, until the Seal Islands were reached. Here, awaiting a favorable condition of the ice, we pushed out into the stream and commenced the struggle.

Every man was armed with an oar, a pole or an axe, and all of these were vigorously applied in forcing our way through the ice and the current. For a time we made fair progress, but were soon caught in the grip of the ice-pack, and hurried down with the stream toward the sea.

After considerable strenuous effort we regained open water. This struggle was repeated several times, but finally we succeeded in reaching, as we supposed, the stationary ice of the shore; but were sorely disappointed to find that it was only a jam in the middle of the channel.

We were now in a dilemma. It was impossible to tow around either end of the jam, and we were being carried to sea.

Finally we concluded to portage across the island of ice and launch on the other side. Accordingly the boat was unloaded and our goods safely carried across; but the ice, we found, would not carry the boat, so we were obliged to cut a channel right through the island the full width of the boat. The boat was then hauled through, re-loaded, and again pushed out into the flowing pack, which, in spite of all our endeavors, carried us far down toward the mouth of the river.

At length we succeeded in getting within thirty feet of the solid south shore ice, but we were again nipped in the floe and carried helplessly downward until, it seemed as if after all we were going out into the bay.

We used every effort to free the boat, but all of no avail. At last, however, civil war among the floes caused a split and brought us deliverance. A few rapid strokes and our old craft bumped the solid ice.

Our bowsman, Francois, quick as a flash sprang ashore with the end of the tow-line, whilst the rushing ice again caught our boat and bore it downwards. Francois held on to the tow-line, but the tug of war was going against him. Finally, anchoring himself against a hummick of ice he succeeded in holding us fast until others sprang out to his assistance.

All hands quickly disembarked, but as there was still a full mile of rough ice, liable to break adrift at any time, lying between us and the shore, no time was lost in exultation; and although the rough ice made travelling difficult, we soon found ourselves on *terra firma* again, rejoicing that the Nelson was at last to north of us.

As we were all much chilled from our exposure in crossing the river, a fire was at once made in the edge of the woods, around which, with feelings of deep satisfaction, our party assembled.

A little of the pounded dried fish still remaining was fried on a pan, with seal oil, which, although not very palatable, was eaten with considerable relish.

After partaking of our light refreshments and the stiffness had been thawed from our limbs, snowshoes were again adjusted, and, with a "Hurrah for York," our tramp continued.

One more camp was made, and on the following day, being the 24th of November, at about eleven o'clock in the morning, we reached York Factory.

Here we were kindly received by the officer of the Hudson's Bay Company, Dr. Milne, a young Scotchman. Our men were given lodgings and rations in one of the many vacant houses of the Fort, whilst my brother and I were shown into the Doctor's bachelor quarters and allowed to occupy the room of Mr. Mowat, the assistant trader, who was absent from York at the time. Here we were able to have a bath, which added greatly to our comfort. With travellers in the north, particularly during the winter season, the practice of performing daily ablutions is quite unheard of. This is not due to neglect, but is rather an enforced custom, due to the painful effects produced by the application of ice-cold water to the skin. During the previous summer and autumn my brother and I adhered to the habit of daily washing our hands and face, until our skins became so cracked and sore that we were forced to discontinue.

Besides Dr. Milne, Mr. Macpherson, a servant, and Mr. Mowat were the only white residents of York.

Mr. Mowat had, only a few days before our arrival, been sent off with two Indians as a relief party to look for the Company's autumn mail, which was now more than six weeks overdue. The mail should have come down the Hays River from Oxford House, two hundred and fifty miles distant, before the close of navigation; but as nothing had yet been heard of it, or the party, grave fears were entertained as to their safety.

As to York Factory, it is one of those places of which it may be said "the light of other days has faded." In the earlier days of the Hudson's Bay Company it was an important centre of trade, and the port at which all goods for the interior posts were received, and from which the enormous harvests of valuable furs were annually shipped. In 1886, when I formerly visited York, there was a white population of about thirty, besides a number of Indians and half-breeds, in the employ of the Company; but as the local supply of furs had become greatly diminished, the staff of servants had been dismissed or removed, until York was now almost a deserted village.

One of the first duties receiving our attention upon reaching York, was the placing of poor crippled Michel in the doctor's hands. His frozen feet, still fearfully sore, were carefully examined and attended to. As he was now in good hands, it was thought advisable to leave him, so with as little delay as possible, preparations were made for the continuance of our journey.

Our faithful guide, "Jim," could now go no farther, so we were obliged to secure the services of another, which we did, and found him to be another brother of Jim's, called Charlie.

After fitting up two dog-teams and procuring necessary supplies, we were ready for our twelve days' trip to Oxford House. Through the kindness of the doctor we were offered the assistance of a third team for two days, which we gladly accepted, as we were somewhat overloaded.

The rations were divided equally, and consisted of 1 lb. bacon, 1$\frac{3}{4}$ lbs. flour, $\frac{1}{4}$ lb. sugar and $\frac{1}{8}$ lb. tea per man per day. This was to carry us through the trip or we must suffer the consequences.

On Tuesday morning, the 28th of November, the second stage of our sledding journey was begun. The dog-sleds now used were flat, somewhat the shape of a large toboggan, this type being better suited to the woodland travel, where the snow is soft and deep.

The condition of our party on leaving York was vastly different from what it had been on leaving Churchill. Our two hundred mile tramp had hardened our muscles, so that with the ten days' rest on the banks of the Nelson, and a four-days' rest at York, we were now in first-class walking trim.

Our first day's tramp was on the ice of the Hays River, which at times was so rough that we were obliged to take the shore. The banks, as we passed, were well wooded with spruce and a few poplar trees, while the adjoining country was of a low, rolling character.

Our course on the second day led through the woods to the north of the river, and by many winding ways we tramped on, following the track of our guide, who we soon found was a very inferior man to his brother, but as track-breaking was now more difficult work than it had been on the harder snow of the open country, his duties were rather more laborious. On this account one of our own men often broke the track, and the guide, merely giving directions as to our route, followed after. During the day's march much of the country passed through had been burnt over some years previous, and was covered with wind-falls and a scrubby second-growth. But little standing timber remained, and in many places the cold, cutting west wind, having little to break its force, almost froze our faces.

On the morning of the third day our assisting team from York, leaving its load with us, returned to the Fort. A readjustment of our loads was then made, and with two remaining teams heavily loaded, we pushed on, though now more slowly.

The problem of getting home had now apparently resolved itself into one of leg endurance, and so, with little variety in the cold wintry woodland scene, we continued the tramp.

At about noon on the 1st of December we were pleased to meet Mr. Mowat, returning with a long-looked-for mail and party, all safe. The great delay in the arrival of the mail had been caused by one of the Indians becoming seriously ill soon after leaving Norway House, and having to return to that post. When he had sufficiently recovered to again take to his canoe, he and his companion started on, reaching Oxford House in safety, but too late to proceed further by canoe. They were therefore forced to wait and complete their journey on snowshoes, and were already on their road when Mr. Mowat met them. Thinking that the mail packet might possibly contain letters for my brother or myself, Mr. Mowat kindly consented to open it, but nothing was found for us. We had expected to have been home before this time, and having little idea as to what way we would return, we had not been able to leave our friends any certain address. After a brief halt we pushed on, and each party now had the advantage of the track made by the other.

The temperature now remained pretty steady at about 25° below zero; but, with the exertion of the tramp during the day and the shelter of the blankets and the warmth of the camp fire at night, we managed to keep pretty comfortable.

About sixteen miles beyond a large stream known as Fox River, an old ox track was reached. This in earlier days had been travelled by oxen and Red River carts, and over it hundreds of tons of freight had annually been hauled; but now it was so grown up with trees that it often required the skill of the guide to keep it. This track lead directly to Oxford, so that from this point onward it was our road, unless when lakes were met with, and then their surface was the preferable track.

Since leaving the banks of the Hays River, no timber of any value had been seen. The wood had all been black spruce of a very scrubby character, but now poplar, birch and jack-pine were occasionally to be seen.

On December the 5th the temperature ran down to forty degrees below zero—fine, cool weather for travelling and sleeping under a spruce tree. In this temperature we found difficulty at times to keep warm, and as we gathered about the camp fire at night, we found ourselves roasting and freezing simultaneously, reversing our positions occasionally, only to reverse the process. Our meals were served on hot pans, but were sometimes frozen before they could be disposed of.

During the afternoon of the 4th and the morning of the 5th of December we crossed Deer Lake, 27 miles in length, and at either end of the lake we found camps of Indians. From one of them we purchased some fine whitefish, which they were catching through the ice, but losing little time, the old ox track was again discovered, and our tramp continued through the woods. By this time our guide, Charlie, had become pretty badly used up by the march, so that he was no longer able to keep the lead, but our own men managed to keep the track and Charlie hobbled along behind.

During the evening of the 6th and the morning of the 7th of December we crossed a succession of thirteen small lakes and some flat open plains, but on the afternoon of the latter day saw a marked change in the character of the country. With the exception of two or three isolated patches, we had seen nothing in the shape of timber of any value since leaving Churchill, but now we had reached a heavy forest of white spruce, jack-pine, poplar and birch trees, and the change was a very pleasing one.

For a distance of six or eight miles we tramped through this heavy forest, and then, just at night-fall, reached the shore of Buck Lake, an extension of Oxford Lake. Unfortunately my brother's feet had become very sore during the day, so that he had been obliged to walk with only one snow-shoe. On this account we had fallen several miles behind the leaders of the party, and when we arrived at the shore of the lake nothing could be seen of our outfit ; and, because of darkness and the hard surface of the snow, it was difficult to follow their track. At times we were obliged to go on our hands and knees in order to do so.

On reaching the shore we knew not which way to turn, but by the aid of a paper torch we soon discovered the tracks into the woods, which, owing to the deep snow, we were now able to follow. A quarter of a mile farther and we were again at the edge of the woods, where, to our glad surprise, and but a short distance ahead, flashed out the lights of Oxford House.

A few minutes later we were the guests of Mr. and Mrs. Isbister, one of the most hospitable old couples it has ever been my good pleasure to meet. Mr. Isbister was the local agent of the Hudson's Bay Company, and was a thorough old-time Canadian, one of those men filled with reminiscences of early Canadian life in the north, and whose many stories are a delight to the listener.

Having reached Oxford in safety, preparations were at once commenced for our journey to the next post, Norway House, one hundred and fifty miles farther on. Some delay was here occasioned in getting dogs, but at length three miserable, half-starved teams were secured, and, with a new guide and drivers, we set out on the third stage of our winter journey. Without narrating the many little incidents by the way, which were very largely a repetition of those of the former part of the trip, I need only say that, after a six days' tramp with the thermometer in the neighborhood of 40 degrees below zero, we arrived safely at Norway House, an important Hudson's Bay Company post, situated at the northern extremity of Lake Winnipeg. I should have said that two of the dog teams procured at Oxford had been intended to haul my brother and myself, and for a time they did so; but the poor animals were in such a wretched condition from the effects of former hard work, that we preferred to walk most of the time, and before we reached Norway House considered ourselves fortunate that we escaped without having to haul the dogs.

Having reached Norway House the difficulties of our journey, so far as my brother and myself were concerned, were practically ended. Sufficient good strong dogs were here available to admit of us travelling in carryalls for the remaining four hundred miles still separating us from West Selkirk, the northern terminus of the railway, but of course our Indians had to stick to their snowshoes. It was here decided to divide our party and send the three western men home—assisted by the team of Eskimo dogs which had accompanied us the whole six hundred miles from Churchill—on foot up the valley of the Saskatchewan River, that being their most direct route. In taking it they would reach their several homes within about the same distance that we would have to travel in reaching Selkirk, namely, four hundred miles. Arthur Owman, the driver from Churchill, chose to go up the Saskatchewan with the western men, so that of our original party there only remained the two Iroquois, Peter and Louis, to accompany my brother and myself. With the least possible delay, four good dog teams, as many drivers and a guide, were procured from Mr. Macdonald, the Hudson Bay Co.'s factor, who showed us much kindness, and two days before Christmas the last and longest division of our journey was begun.

My brother and myself were now warmly rolled up in robes and blankets and lying in our carryalls. Our supplies and baggage were all loaded upon the two remaining sleds, and with a driver trotting along beside or behind each team, the guide running before, and the two Iroquois sometimes before and at other times behind, we travelled on an almost due south course over the ice along the shore of Lake Winnipeg. About the same time that we started for the south, the other section of our party set out across the lake to the westward for the mouth of the Saskatchewan River, the course of which they were to follow to their homes.

Our teams, of four dogs each, consisted chiefly of fine, powerful animals, and we soon found that there was no further necessity of my brother or me exerting ourselves more than we desired. The teams travelled all day, and indeed day after day, at a rapid trot, sometimes breaking into runs, so that it gave the Indians all they could do to keep up with them. Halts were made once during the morning, at noon, and once during the afternoon to rest the dogs; and in the evening camp was made on the shore in the woods as on the earlier parts of our journey. Some parts of our road were very rough and lumpy, making the footing bad for both men and dogs. It also made travelling scarcely less disagreeable to us who rode, for as our carry-alls rattled and bumped over the lumps, we, lying upon our backs without room enough to move, received the full benefit of every bump.

But taking rough and smooth together, we travelled on, making an average of about forty miles per day, and some days making as much as forty-six or forty-seven miles. When we had made about half our distance to Selkirk, and were in the neighborhood of a fishing station at the mouth of Berens River, poor Peter, the Iroquois, played out, but being fortunate in meeting a man who was teaming fish to Selkirk, we secured a passage for Peter, and ourselves pushed on. When we had made about another hundred miles, Louis, the remaining Iroquois, also became crippled; but again arrangements were made to have him driven in with a horse and sleigh, and without delay we pushed on. As the force of gravitation increases inversely as the square of the distance, so our anxiety to get in increased as the end of our journey drew nearer, and at length, after a long and rapid trip which occupied ten days, on the evening of the 1st of January, 1894, under the light of the street lamps of the little town, our teams trotted up the streets of West Selkirk, and thus our canoe and snowshoe journey of three thousand three hundred miles was completed.

I need hardly say that the telegraph office was soon found and messages despatched to our anxious friends, who for six months past had not been able to hear from us.

AIR COMPRESSORS.

By H. V. Haight, Grad. S.P.S.

No one who is at all interested in engineering can fail to be impressed with the importance of the applications of compressed air. Though some of its uses have been known for hundreds of years, and though it has been used in mining, tunnelling and similar work for a long time, yet it is only lately that compressed air has begun to receive the attention that it deserves. As evidence of its recent development we might point to the compressed air journal, *Compressed Air*, which has been published since the beginning of 1896, and to the fact that, since the beginning of the present year, the *Engineering Magazine* has devoted to compressed air a special department of its index of technical literature. One can hardly pick up a technical journal without seeing some reference to the uses of compressed air; and, even the newspapers have given descriptions of the pneumatic street cars now running in New York City. We have been somewhat behind European countries in our recognition of the possibilities of compressed air. For over ten years there has been in operation in Paris a pneumatic system of power-distribution, and for some time street cars run by compressed air have been in operation in France and Switzerland.

While the uses of compressed air are receiving so much attention, not much appears to be generally known regarding the methods of compressing air. This paper is intended to present in concise form some of the information regarding air compressors which is scattered through various books, periodicals and catalogues.

The most common form of air compressor is the direct-acting piston compressor. The air cylinder of the Air Brake Pump shown in Fig. 4 will serve to illustrate the action of compressors of this kind. On the down stroke air is drawn in above the piston through valve I, while at the same time the air below the piston is compressed and forced out through valve D^1. On the up stroke air is drawn in at I^1 and forced out through D.

Air at very low pressures, such as the blasts used in blowing fires, cleaning grain, ventilating buildings and mines, etc., is furnished by bellows, rotary blowers, or fans, but these machines are not generally classed as air compressors, and both in theoretical treatment and design they are usually very different from the kind first mentioned.

The most common method of driving a compressor is by direct connection to a steam engine, the two pistons being on the same rod, as shown in Figs. 4, 13, 14, 15, etc. Other methods of driving are by direct connection to a water-wheel, as in Figs. 21 and 22, or by belting or gearing, from a shaft to which power is furnished from some source. (Figs. 10, 11 and 18.)

USES OF COMPRESSED AIR.

In order to get a fair idea of the requirements of a well-designed compressor, we should understand some of the uses to which compressed air is put, as a design which would be correct under one set of conditions might be quite unsuitable under other circumstances. There are some two hundred distinct uses of compressed air, not including those in which it merely produces rotary motion in general, the compressed air motor taking the place of a steam engine, electric motor or some other means for furnishing power. Hence, we must necessarily limit ourselves to a few of its uses, and we will choose such uses as will best illustrate the different requirements in the design of air compressors.

One of the earliest uses of compressed air of which we have any record, is in connection with work done under water, in diving apparatus, bridge caissons and tunnels. The pressures used are generally low, from 10 to 25 pounds per square inch. It is difficult for men to work under high pressure. In the construction of the gas tunnel under the East River and Blackwell's Island, at New York, the pressure in the tunnel was 48 pounds. The pressure was so great that the workmen could remain only two hours at a time in the tunnel, and several of them died from the effects of it. It is evident that a compressor for this service should be *reliable*. It should be simple, strong, portable, capable of working under a considerable range of pressures, or of being run at a high speed in an emergency. All these points would probably be considered more important than steam economy.

Next to its use for work under water, one of the earliest uses of compressed air, and one which still employs probably one-half of the compressed air that is used for mechanical purposes, is in driving rock drills and other machinery in mining and quarrying, or in the construction of canals and tunnels. The pressures used vary from 50 to 100 pounds per square inch—60 pounds being a common pressure. The requirements of a compressor for this service will, of course, vary considerably with the location, altitude, transportation facilities, etc. We might say, in general, that economy of steam and durability are the most important requirements. Mines are often situated at a considerable distance from a source of supplies, so that coal is dear, and repairs are troublesome and expensive. In the case of a coal mine, however, steam economy would have little weight, except, perhaps, as far as it affected the size of boilers necessary to supply the steam. For high altitudes, the compression cylinder must be made larger for the same power capacity. Where water-power is available, of course the compressor would require to be designed to suit the hydraulic conditions.

In some large cities, notably in Paris, there are large central stations, with pipe systems running to all parts of the city, for the purpose of supplying compressed air for numerous purposes. In large plants of this kind the greatest attention can be paid to the production of compressed air at the lowest power cost.

The automatic air brakes on railroad trains are operated by compressed air furnished by the air-brake pump, placed on the locomotive. The fact that these "pumps" have been in use a number of years, that there are about 30,000 of them in service, and that other designs have been tried and discarded, makes it probable that the design is the one which is the most suitable under the circumstances; and yet they use steam in the most wasteful manner that one could imagine. The air-brake pump uses nearly ten times as much steam for the same service as would be required by the best modern air compressor, and yet it is "the one compressor whose extravagant waste of steam is fully condoned by the circumstances surrounding its employment." The pump is very simple, and is always ready for service, and the steam used is mostly that which would otherwise be blown off at the safety valve of the locomotive while stopping at stations or running down grade.

Air at a comparatively low pressure—from two to four pounds per square inch—is used in blast furnaces. The machines which furnish the blast are called blowing engines, and are very similar to ordinary air compressors, except that no attempt is made to cool the air during compression. Fig. 31 shows the construction of the air cylinder of a blowing engine.

Air at a very low pressure is also used in the systems of pneumatic tubes for the transfer of mail matter and other parcels. In Philadelphia, where a line of tubes has been installed, the pressure at the main station is seven pounds, and at the sub-station, half a mile away, it is four pounds. The compressor at the main station furnishes power for both the outgoing and the return tubes. In New York City, the pneumatic despatch tubes of the Western Union Telegraph Company are operated partly by direct pressure and partly by vacuum.

In the pneumatic switch and signal systems it has been found advisable to use air at a low pressure. Ten pounds is the pressure used in some cases.

Mining locomotives are often run by compressed air, carried in strong tanks under high pressure. The high pressure is necessary on account of the comparatively small reservoir which the locomotive can carry. The pressures used vary from 350 to 700 pounds per square inch. The compressor must, of course, be designed for this high pressure. As we will see later, compression in two or more stages is almost absolutely necessary for high pressures. In some cases these compressors take air from the general mine service at 80 pounds, and compress to the pressure required by the locomotive.

Compressed air is also used for running street cars. As the reservoirs of these cars must necessarily be small, and the cars must make long trips, the pressures used are sometimes very high, 2,000 pounds per square inch being used in some cases. Even this does not represent the highest pressures used, as the cars are sometimes charged from a large stationary reservoir, in which air is stored under a higher pressure.

Very high air pressures are also used in connection with dynamite guns. The pressure actually used in the gun is about 1,000 pounds per square inch, but in order that several shots may be fired without running the compressor, it is necessary to store the air at a considerably higher pressure—2,000 pounds or more. It will be readily seen that the requirements of a compressor for this service are in many respects quite exceptional, but we shall refer to this more fully when describing a compressor recently built for this purpose.

Air compressors are used on board ship for different purposes.

In this case one very essential requirement is economy of space. On men-of-war the compressed air is used in dynamite guns and for propelling the Whitehead torpedo, in both of which a pressure of about 1,000 pounds per square inch is used. It has lately been proposed to use compressed air on men-of-war for many other purposes also, such as running pumps, operating turrets, etc. On board the ships which carry meat from Australia, compressed air refrigerating machines are in use. The air is compressed in one cylinder to about fifteen atmospheres, thoroughly cooled, and then expanded in another cylinder to about five atmospheres. The exhaust is used for cooling and is then compressed again. This system is known as dense-air refrigerating.

If we examine the question of the design of an air compressor or an air compressing plant, we shall see that in this, as in almost every engineering problem, the underlying principle is economy. We must not, however, consider the matter in any narrow sense, but must take into consideration all the circumstances which bear on the question, giving to each its proper weight. Advantages must be set against disadvantages in order to arrive at a combination which will, on the whole, be the least expensive, considering the results to be obtained.

THERMODYNAMICS OF AIR COMPRESSION.

The changes which occur in the properties of the air contained in the cylinder of an air compressor, may be represented graphically by plane curves, taking as co-ordinates any two of the independent properties of the fluid. The curve most commonly employed, is the one whose co-ordinates are pressures and volumes. With these co-ordinates, we are able to compare our results with the diagrams drawn by an indicator. It is usual to assume that air follows the laws of perfect gases, as expressed by the equation

$$pv = RT$$

The adiabatic equation is

$$pv^k = \text{Const.}$$

And the isothermal is

$$pv = \text{Const.}$$

The values usually taken for the constants are:

$$p_a \begin{cases} = 14.7 \text{ pds. per sq. inch.} \\ = 2,116.8 \text{ pds. per sq ft.} \end{cases}$$

$$R = 53.22$$

$$T = t + 461$$

$$k = 1.41$$

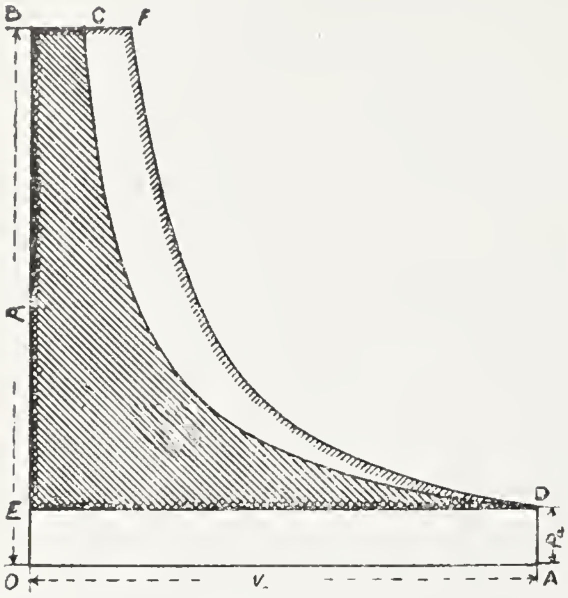

FIG. 1.

Fig. 1 represents an ideal diagram, without clearance or valve resistance. We shall assume that the curve of compression is of the form $pv^n = \text{Const.}$, where the value of n will depend upon the degree of cooling during compression.

During the process ED air is drawn in at atmospheric pressure and does the work on the piston

$$p_a \, v_a$$

During the process DF this air is compressed to the receiver pressure p_1, the work done being

$$\frac{p_1 v_1 - p_a v_a}{n - 1}$$

During the process FB this air is expelled at constant pressure, the work done being

$$p_1 v_1$$

The total work of compression and delivery of one pound of air is

$$U = \frac{p_1 v_1 - p_a v_a}{n - 1} + p_1 v_1 - p_a v_a$$

$$= \frac{n}{n - 1} (p_1 v_1 - p_a v_a)$$

$$= \frac{n}{n - 1} p_a v_a \left(\frac{p_1 v_1}{p_a v_a} - 1 \right)$$

$$\text{Now } \frac{v_1}{v_a} = \left(\frac{p_a}{p_1} \right)^{\frac{1}{n}}$$

Inserting this in the above equation we get

$$U = \frac{n}{n - 1} \, p_a v_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} - 1 \right] \qquad (1)$$

$$\text{But } p_a v_a = R T_a$$

Inserting this we get for the work of compression and delivery of one pound of air

$$U = \frac{n}{n - 1} \, R T_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} - 1 \right] \qquad (2)$$

Since p_1 and p_a occur as a ratio we may take them in any convenient units, such as pounds per square inch or atmospheres, instead of in pounds per square foot.

During compression the temperature rises and the final temperature may be obtained from the equation

$$\frac{p_1}{p_a} = \left(\frac{T_1}{T_a}\right)^{\frac{n}{n-1}}$$

$$\text{Whence } T_1 = \left(\frac{p_1}{p_a}\right)^{\frac{n-1}{n}} T_a \qquad (3)$$

The temperature of the compressed air usually falls, in the receiver and pipes, to the initial temperature T_a, the heat given out being

$$\begin{aligned} Q &= C_p\ (T_1 - T_a) \\ &= C_p \left[\left(\frac{p_1}{p_a}\right)^{\frac{n-1}{n}} - 1\right] T_a \qquad (4) \end{aligned}$$

Adiabatic Compression.—Equation (2) becomes

$$U = \frac{k}{k-1}\ R\,T_a \left\{\left(\frac{p_1}{p_a}\right)^{\frac{k-1}{k}} - 1\right\} \qquad (5)$$

When the initial temperature is 60° F. this becomes

$$U = 95{,}630 \left[\left(\frac{p_1}{p_a}\right)^{0.29} - 1\right] \qquad (6)$$

Inserting the value of $\left(\frac{p_1}{p_a}\right)^{\frac{k-1}{k}} = \frac{T_1}{T_a}$ from (3) in equation (5) and putting $\frac{k-1}{k} R = \frac{C_p}{A}$ equation (5) reduces to $U = \frac{C_p}{A} \left[T_1 - T_a\right]$

That is to say, the whole work of the adiabatic compression and delivery of one pound of air is equal to the heat generated during compression and given out when the air cools down, at constant pressure, to its original temperature.

Isothermal Compression.—If the compression follows the isothermal line DC (Fig. 1)

Work of atmospheric pressure $= p_a v_a$

Work of compression $= p_a v_a \log_e \frac{p_1}{p_a}$

Work of delivery $= p_1 v_1$

But $p_1 v_1 = p_a v_a =$ Const.

∴ Work of isothermal compression and delivery of one pound of air is

$$U = p_a v_a \log_e \frac{p_1}{p_A} \tag{7}$$

$$= RT_a \log_e \frac{p_1}{p_a} \tag{8}$$

When the initial temperature is 60° F. this becomes

$$U = 27{,}710 \log_e \frac{p_1}{p_a} \tag{9}$$

Two Stage Compression.—Air is often compressed in two or more stages, passing through an intercooler on its way from one cylinder to the next, and having its temperature reduced nearly to the initial temperature. Assuming that the intercooler is very large and that the temperature of the air can be reduced to the initial temperature in passing through it, we have the processes as shown in Fig. 2.

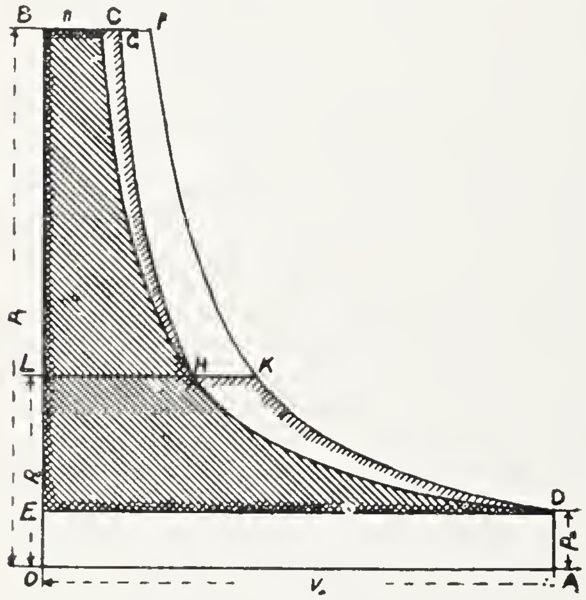

FIG. 2.

During the process ED air is drawn in at atmospheric pressure. From D to K it is compressed in the first cylinder to the pressure p_c. In the process KL it is forced out into the intercooler. During the process LH it is drawn into the second cylinder, during HG it is compressed, and during GB it is delivered at the pressure p_1. The work of compression and delivery of one pound of air is

$$U = \frac{n}{n-1} RT_a \left[\left(\frac{p_c}{p_a}\right)^{\frac{n-1}{n}} + \left(\frac{p_1}{p_c}\right)^{\frac{n-1}{n}} - 2\right]$$

Equating the first differential to zero we get the value of p_c which will make the work a minimum

$$p_c = \sqrt{p_a p_1} \tag{10}$$

Inserting this value in the above equation we get

$$U = \frac{2n}{n-1} RT_a \left[\frac{p_1}{p_a}^{\frac{n-1}{2n}} - 1\right] \tag{11}$$

Three Stage Compression.—By a similar method we get the minimum work of three stage compression to be

$$U = \frac{3n}{n-1} R T_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{3n}} - 1 \right] \tag{12}$$

Mean Effective Pressure.—From equations (1) and (7) we may obtain the value of the mean effective pressure for the process. Dividing by v_a we get

$$\text{Adiabatic} - \text{M. E. P.} = \frac{k}{k-1} p_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{k-1}{k}} - 1 \right] \tag{1a}$$

$$\text{Isothermal} - \text{M. E. P.} = p_a \log_e \frac{p_1}{p_a} \tag{7a}$$

Tables have been calculated and may be found in books on compressed air, giving the mean effective pressure of both adiabatic and isothermal compression to different pressures. They are very useful for making calculations of the power required by a compressor or in comparing the actual work of compression with the ideal.*

Efficiency.—The work of isothermal compression is taken as the standard in determining the efficiency of compression. It represents the ideal and unattainable, but still the only rational standard. The excess of work over that of isothermal compression represents the work uselessly expended in overcoming valve resistance and in heating the air during compression. This heat is lost when the temperature of the compressed air falls to the initial temperature, as it usually does before the air is used.

Dividing (8) by (2) we get the efficiency of single stage compression, under the assumed conditions

$$E_1 = \frac{\log_e \frac{p_1}{p_a}}{\frac{n}{n-1} \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} - 1 \right]} \tag{13}$$

For two stage compression, dividing (8) by (11) we get

$$E_2 = \frac{\log_e \frac{p_1}{p_a}}{\frac{2n}{n-1} \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{2n}} - 1 \right]} \tag{14}$$

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*The writer has found the tables in "Compressed Air" by Frank Richards to be very useful.

For three stage compression, dividing (8) by (12) we get

$$E_3 = \frac{\log_e \frac{p_1}{p_a}}{\frac{3n}{n-1}\left[\left(\frac{p_1}{p_a}\right)^{\frac{n-1}{3n}} - 1\right]} \qquad (15)$$

The following table gives the values of E_1 E_2 and E_3 for adiabatic compression to several pressures.

Gauge pressure.	$\frac{P_1}{P_a}$	E_1	E_2	E_3
29.4	3	85	92	..
58.8	5	78	89	..
88.2	7	74	86	..
132.3	10	70	84	..
205.8	15	66	82	..
499.8	35	57	76	84
1014.3	70	51	72	81
2041.3	140	45	68	78

Effect of Clearance.—If we assume that the air in the clearance expands according to an exponential curve, having the same value of the exponent as the compression curve (which cannot be far wrong), then the air in the clearance acts as a cushion, storing and giving out energy. Then no more power will be required to compress and deliver the same quantity of air, but the capacity of the compressor cylinder will be lessened by the length of E L, Fig. 17, to the whole length of the diagram. This makes it necessary to compress in stages, when high pressures are desired. In compressing to 35 atmospheres (about 500 pounds gauge) for instance, if there were a clearance of even *one per cent.*, the air in the clearance would expand and fill over 30 per cent., of the cylinder, reducing the capacity by that amount.

Equations (2), (5), (6), (8), (9), (11) and (12), giving the work in foot pounds per pound of air compressed, will still apply, but if we wish to make use of the equations giving the mean effective pressure, we must either (1) reduce the M.E.P. by the ratio of E L to the whole length of the diagram, or (2) use the M.E.P. determined by this equation with the actual quantity of air compressed.

Pressure-Temperature Curves.—Some very interesting curves are given by W. L. Saunders, C.E., in connection with his paper on "Compressed Air Production." These are shown in Fig. 3. There are, in fact, two distinct diagrams. The curves starting from the corner A show the relative volumes at different pressures in atmospheres or by gauge (taking the initial volume as unity.) The curves starting from the corner O show the temperature at different pressures during adiabatic compression, the initial temperature being given.

For example, suppose air to have been compressed to seven atmospheres, as shown at the top of the diagram, or 88.2 lbs. gauge, as shown at the bottom; then the volume, had no heat been given out during compression, would have been about 0.25 of the initial volume, while if the air had been cooled to its initial temperature the volume would have been about 0.14 of the initial volume. These quantities are independent of the initial temperature. Had the compression been adiabatic and the initial temperature 0° F., the temperature at 7 atmospheres would have been about 350° F., while if the initial temperature had been 60°, the temperature at 7 atmospheres' pressure would have been about 454° F.

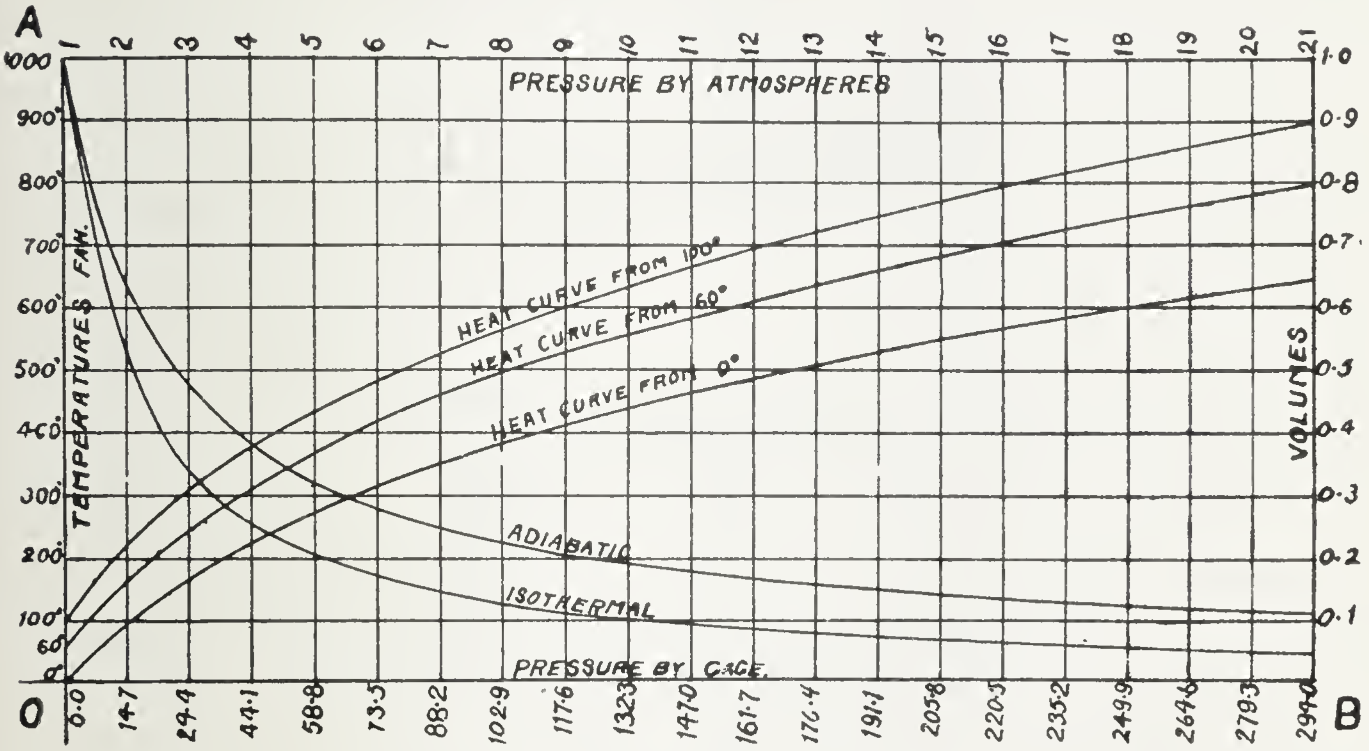
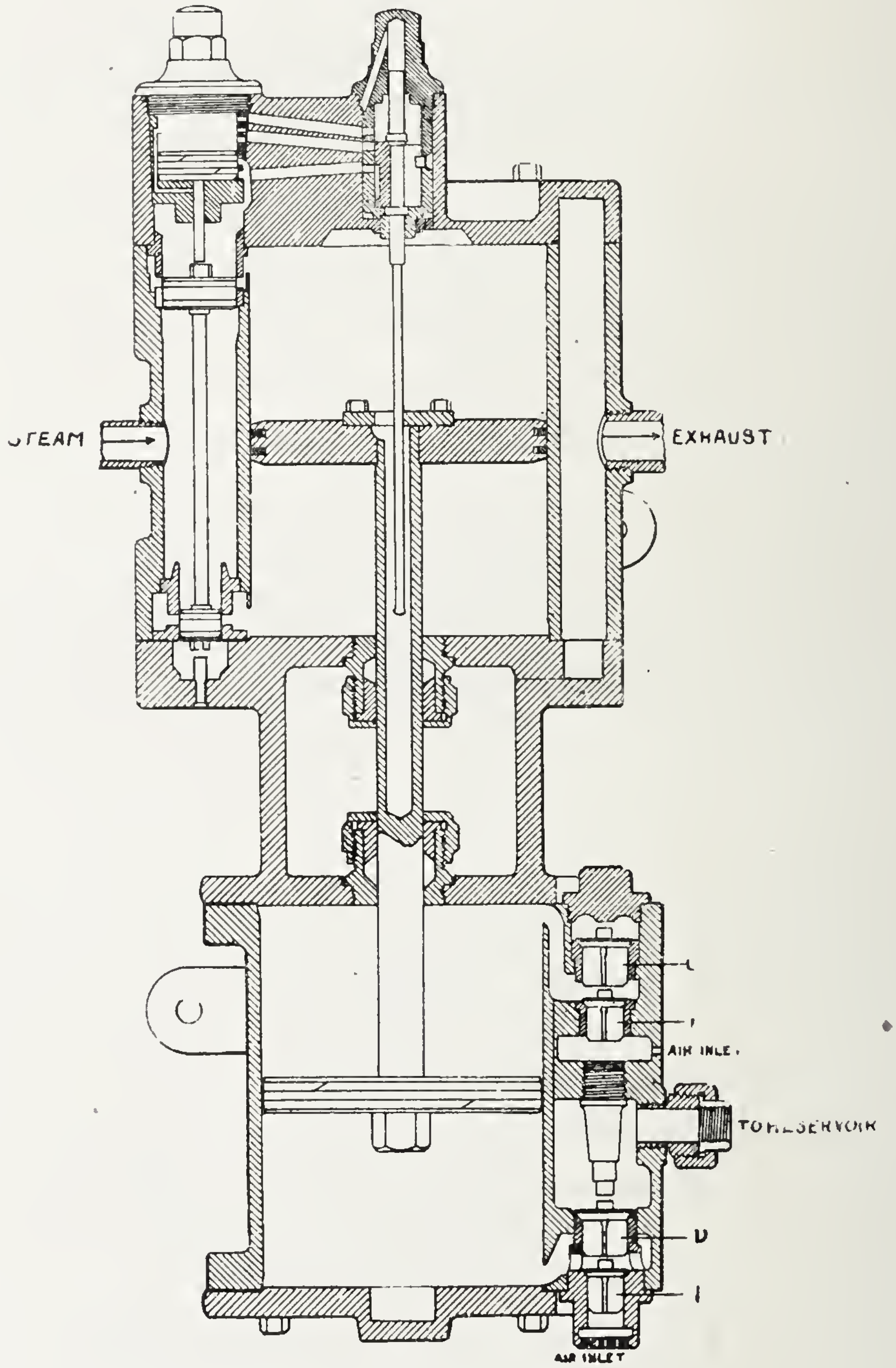


FIG. 3.

An inspection of the temperature lines will show that a high initial temperature corresponds to a high temperature throughout compression, and also to a rapid rise of temperature during compression. This shows the advantage of a low initial temperature.

We can also see the advantage of a low initial temperature from equations (2) (8) and (12). It will be seen that the work of compression varies directly as the absolute temperature. If the temperature of the air which is available for compression is 39° F. or 461 + 39 = 500° by the absolute scale, then every five degrees which this air becomes heated before compression begins represents a loss of one per cent. In the winter there is often a difference of 50 degrees between the air outside the engine room and the air inside of it, so that a saving of ten per cent. might easily be made by a proper attention to the air supply. In almost every form of air compressor the air has a chance to become heated during admission to the cylinder by coming in contact with hot metal. To make matters

Fig. 4. AIR PUMP.



worse, the air is often forced to flow in thin streams over the heated metal. There is evidently a chance for considerable improvement in this particular. This is a loss, however, which is not shown by the indicator, so that very little attention is paid to it, and manufacturers of compressors calmly assume that it does not exist.

REMOVING THE HEAT OF COMPRESSION.

Compressors are often divided into classes, which differ from one another in the methods employed for removing the heat imparted to the air during compression. One classification is into "wet" and "dry" compressors. With "wet" compressors water is used *in* the cylinder during compression to keep down the temperature. Wet compressors are sub-divided into *injection* compressors, in which water is admitted to the cylinder in a spray, and *water piston* compressors, where a body of water moves back and forth with the piston and compresses the air. Figs. 25 and 26 show the compression end of a water piston compressor made by the Humboldt Engineering Company, Kalk, near Cologne, Germany.

In "dry" compressors the whole cooling effect on the air *during compression* must come from the walls of the cylinder and piston. The dry compressor is the kind more commonly used. There is no firm on this continent, so far as can be learned, which regularly manufactures wet compressors, and a great many firms in England and other European countries make only dry compressors. The wet compressor is the earlier type, and it is still used extensively in some places, notably at the power plant in Paris, where there are compressors of 2,000 H. P. each, in which water is injected into the cylinder. In Germany also the wet compressors seem to find considerable favor.

There is, without doubt, considerable to be said in favor of using water in the cylinder during compression. When water is properly introduced in a fine spray, the temperature is kept down throughout compression and the heat loss is very small. In compressing adiabatically to five atmospheres (58.8 pounds gauge) the lost work, due to the heating of the air, is 27 per cent. of the work of isothermal compression. W. L. Saunders, C.E., in his paper on "Compressed Air Production," says that in the old Ingersoll Injection Compressor this loss was reduced to 3.6 per cent., and he quotes a description of a compressor of an European type in which it was reduced to 1.6 per cent. The description given is as follows: "Engine, two vertical cylinders, steam jacketed, with Meyer's expansion gear; cylinders,

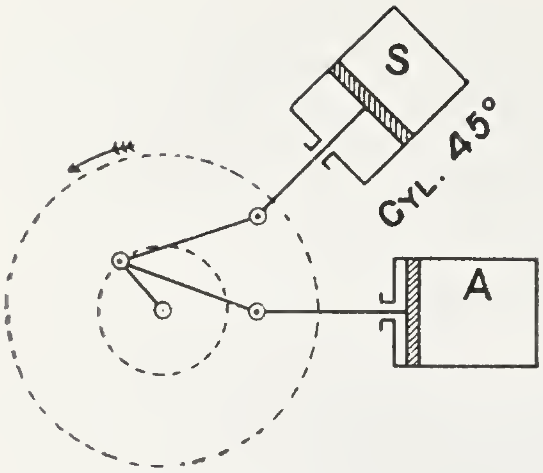


FIG. 5

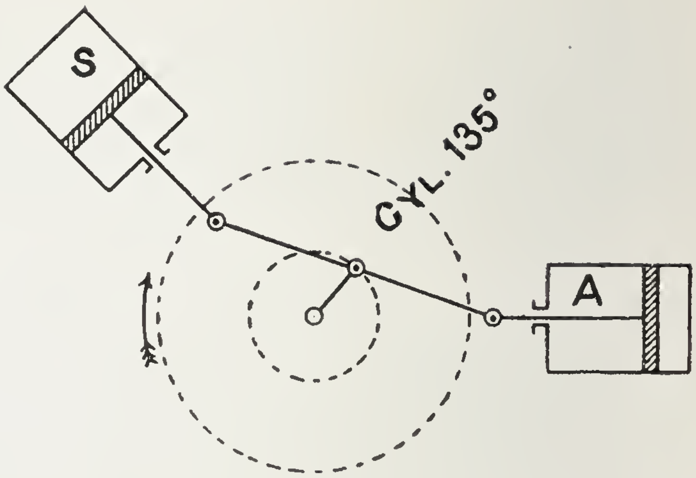


FIG. 6

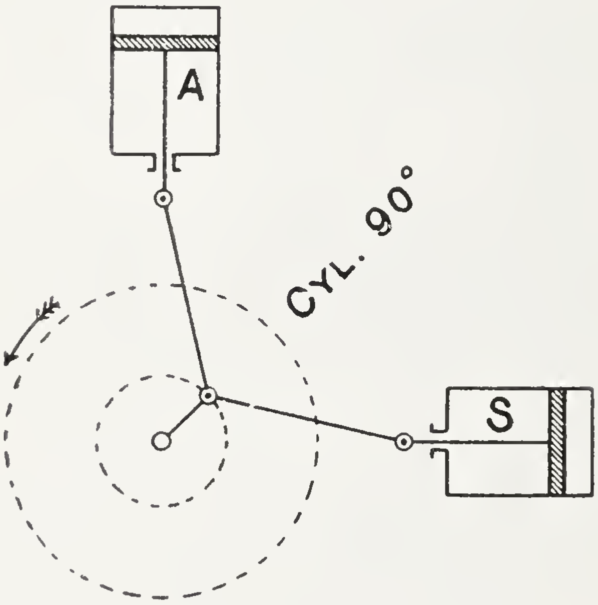


FIG. 7

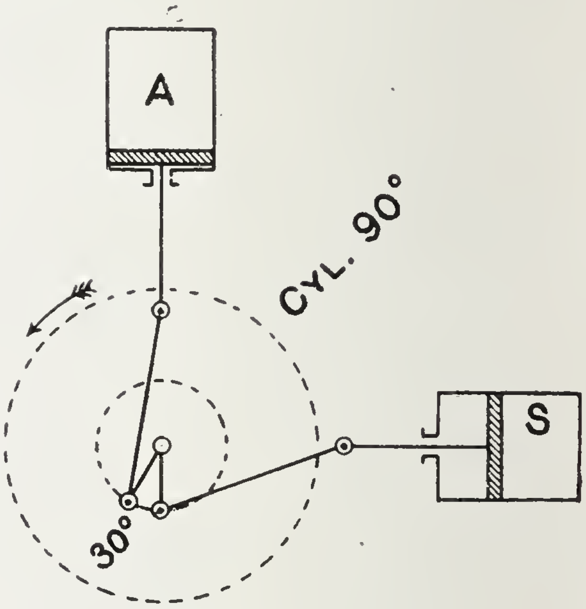


FIG. 8

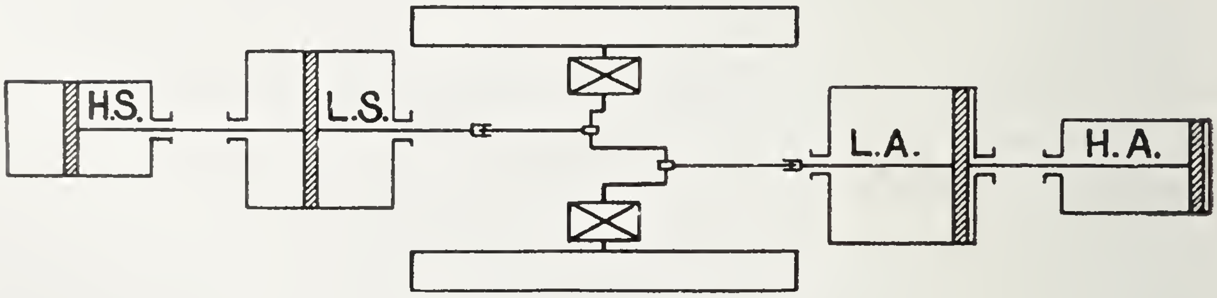


FIG. 9

16.9 inches diameter, stroke 39.4 inches; compressor, two cylinders, diameter of piston 23 inches; stroke 39.4 inches; revolutions per minute, 30 to 40; piston speed 195 to 260 feet per minute; capacity of cylinder per revolution, 20 cubic feet; diameter of valves, viz., four inlet and four outlet, 5½ inches; weight of each inlet valve, 8 lbs.; outlet, 10 lbs.; pressure of air, 4 to 5 atmospheres. The diagrams taken of the engine and compressor show that the work expended in compressing one cubic meter of air to 4.21 effective atmospheres (61.9 pounds per square inch gauge pressure) was 38,128 lb. (it appears to mean meter-pounds; the pound is of course not a measure of work). According to Boyle and Mariotte's law (that is, for isothermal compression) it would be 37,534 lb., the difference being 594 lb., or a loss of 1.6 per cent."

For adiabatic compression, the lost work would have been 28 per cent. of the work of isothermal compression. The temperature of the air on entering the cylinder was 50°F., on leaving, 62°F. The mechanical efficiency was 85½ per cent.

The thermal efficiency of this compressor was remarkably high, the more so when we consider that the calculation from the area of the indicator cards includes in the 1.6 per cent., the losses due to valve resistance also. It should be noted, though, that the friction loss of 14.5 per cent. is quite large, and that the low piston speed would require the machine to be very large and heavy in proportion to its capacity.

The results of experiment and experience all go to show that by the proper use of water in the cylinder during compression the temperature of the air can be kept down and the loss of work due to heating of the air can be reduced beyond what can be expected of mere surface cooling. Other advantages that are claimed for "wet" compressors are as follows:—

(1) Increased volume of air per stroke, due to the clearance spaces being filled with water.

(2) Cold cylinder, preventing the air admitted from becoming heated before compression begins.

(3) Low temperature of air immediately after compression, thus causing the moisture of the air to be condensed in the receiver.

(4) Low temperature of cylinder and valves, thus maintaining the packing.

In order to be efficient as a cooling device, water must be

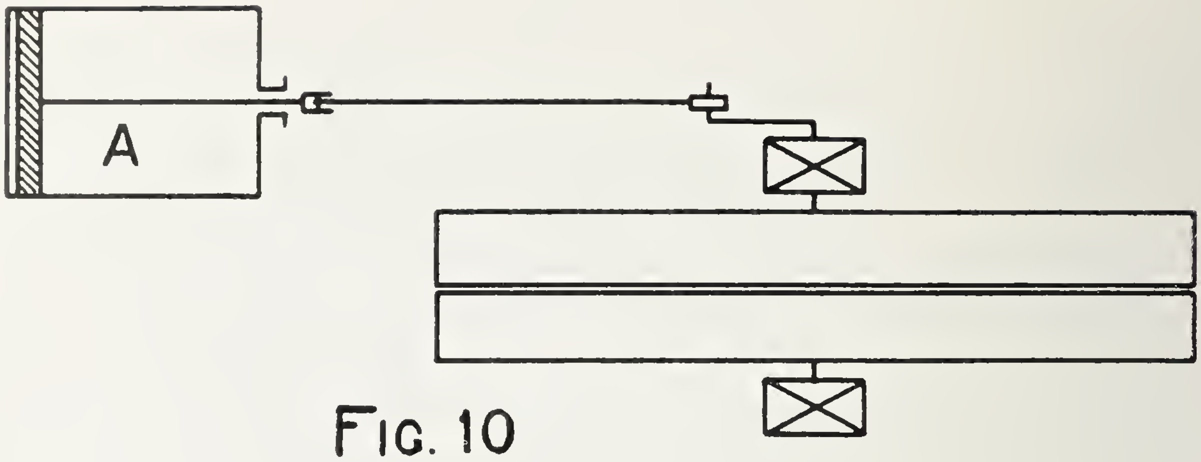


FIG. 10

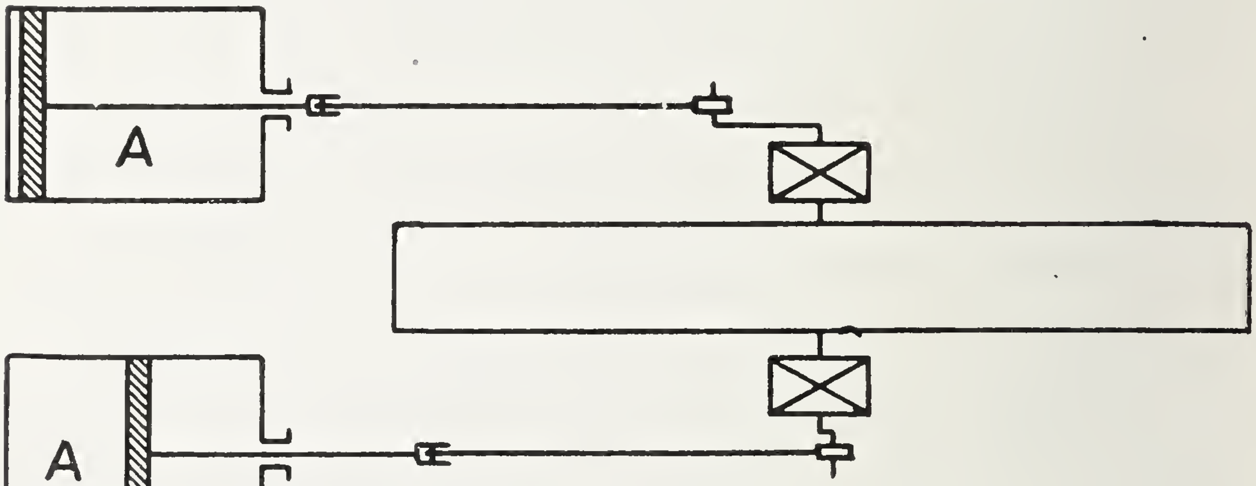


FIG. 11

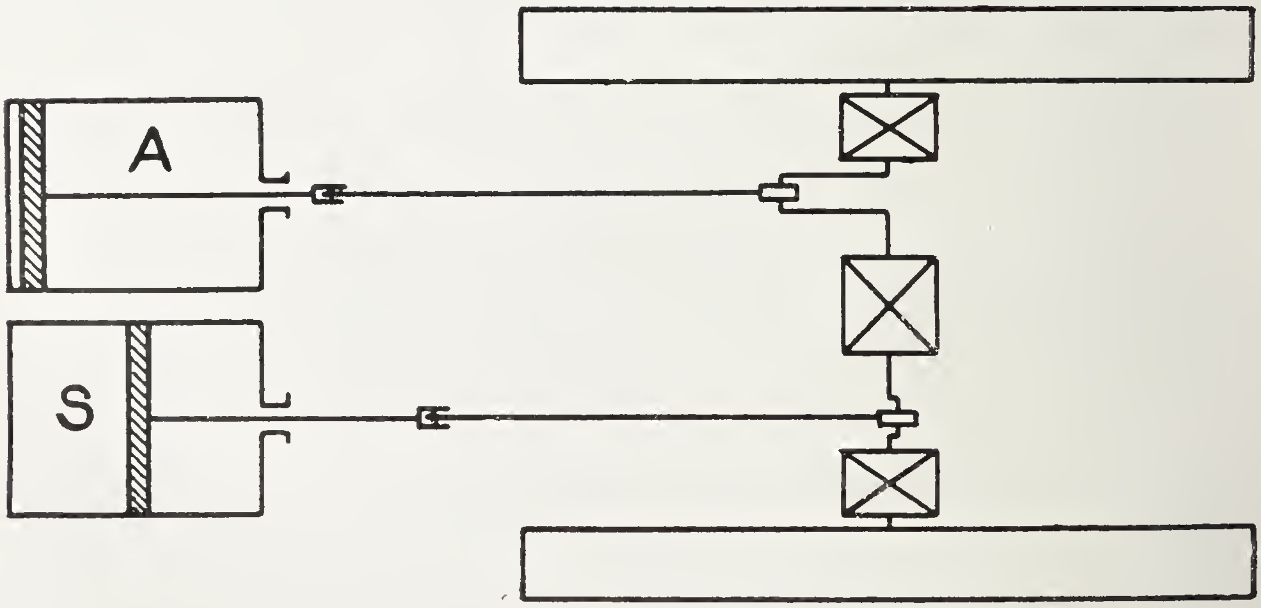


FIG. 12

injected *during compression* in a *fine spray.* Water and air are both poor conductors of heat, so that in order to cool the air its particles must be brought in *contact* with the water. When water is admitted with the air through the inlet valves, it falls at once to the bottom of the cylinder and can have little effect during compression. With water piston compressors the result is much the same; the surface of the water becomes heated and it is then of little further use. It would not be as good as that much surface of cast iron. Cast iron and water have about the same capacity for heat at equal volumes, but cast iron is about eighty times a better conductor than water. When water is used in the cylinder but does not keep down the temperature of the air, then the air will take up moisture and the air delivered will contain much water. The pressure of this water vapor will also increase the work of compression. Other objections to water in the cylinder, besides these two, are as follows:

(1) Impurities in the water act on the surfaces exposed to it.
(2) The presence of water causes difficulty in lubricating the cylinder.
(3) Mechanical complications connected with the water pump and the difficulty of injecting the right quantity of water.
(4) Loss of the power required to move the water in the cylinder.
(5) Absorption of air by the water.
(6) The presence of the water limits the speed of the compressor, because of the danger of breaking the cylinder-head.

Of these objections the most serious is that of the increased wear of the working parts. Even when pure water is used the cylinders wear to such an extent as to produce leakage and require re-boring. The limitation of speed is also of considerable importance. This does not so much affect injection compressors, as they may approach dry compressors in speed; but the hydraulic or water piston compressors are subject to the laws which govern piston pumps, and are limited to a piston speed of about 100 feet per minute. The slow speed of hydraulic piston compressors makes a very heavy and expensive construction necessary. Dry compressors may be run at a piston speed of nearly 500 feet per minute, and injection compressors at over 400 feet per minute.

There is one other method of removing the heat of compression, though it can hardly be called a method of removing the heat *during compression*. It is by compressing the air in two or more stages and

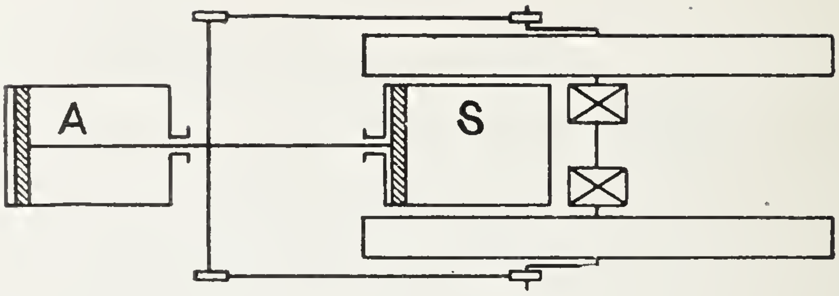


FIG. 13

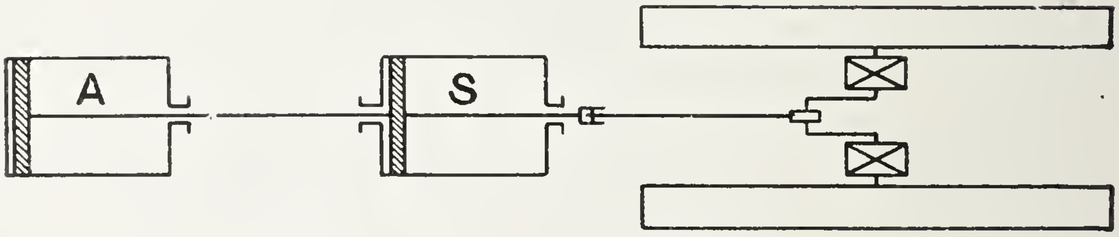


FIG. 14

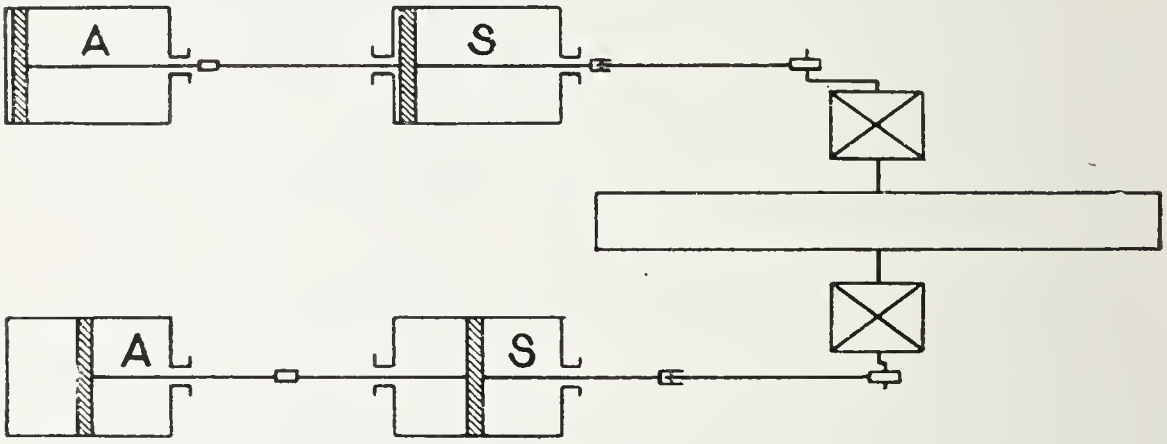


FIG. 15

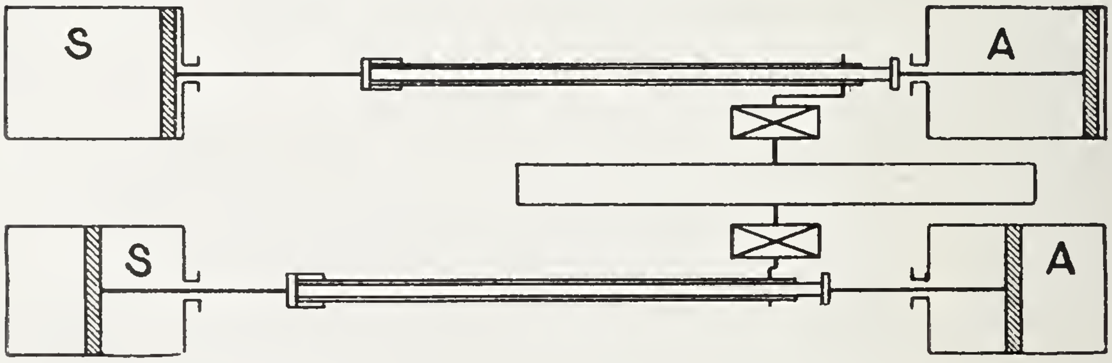


FIG. 16

cooling it between the stages. This method can be made quite efficient, for the intercooler can be made of sufficient capacity to cool the air to the initial temperature. The possible saving is shown by the table previously given of the theoretical efficiency of single-stage, two-stage, and three-stage compression to various pressures. The greatest saving by compounding is effected when compressing to high pressures. It is when compressing to high pressures that the other advantages of compounding, viz., the reduction of the terminal strains and the clearance losses, are the most marked.

This method of cooling may be, and usually is, combined with some other method of cooling. The Norwalk tandem compound compressor shown in Fig. 20 has both water jackets and intercooler. The Riedler compressors used at the power plant in Paris are two-stage compressors with spray injection.

To sum up we may say: Good spray injection will give the highest thermal efficiency; but other considerations make the presence of water in the cylinder undesirable. Water used in the cylinder, except as a spray, is objectionable. Surface cooling by water-jacketed cylinders is not particularly efficient, but has many advantages. Compression in two or more stages, combined with one of the previous methods of cooling, gives excellent results.

VARIOUS EFFICIENCIES.

Let U = work of compression, as calculated from the indicator cards of the steam cylinder.

And U_1 = work of compression, as calculated from the indicator cards of the air cylinder.

Then $\frac{U_1}{U} = E_m$ may be taken as the *mechanical efficiency* of the compressor, including, of course, the friction of both steam and air ends; that is, in reality, E_m is the combined mechanical efficiency of both steam engine and compressor.

U and U_1 may be taken in foot pounds per pound of air compressed. It is more usual to take the work per cubic foot of free air compressed; but in that case we must take both pressure and temperature into account also.

Let U_2 = work of isothermal compression of one pound of air. (See equations (8) and (9).

Then $\frac{U_2}{U_1} = E_c$ may be taken as the *efficiency of compression.* It includes losses due to imperfect valve action, to leakage, to clearance, to heating of the air during admission, and to the rise of temperature during compression. All of these losses except the last may be kept small by good construction. The imperfect action of inlet valves causes throttling during admission, which increases the work of the stroke and decreases the quantity of air admitted. The extra work is represented by the area of the card between the atmospheric line M N, and the admission line A F, Fig. 11. The loss of capacity is represented by the ratio of A K to the whole length of the diagram, A L. This loss of capacity is not necessarily a loss of efficiency, but calculations of efficiency are often made on the basis of the volume of the cylinder, and we must then take the loss of capacity into account. The loss due to imperfect action of the discharge valve is represented by the area of the air-card above the line J.D., representing the receiver pressure, (See Fig. 17). Leakage should not cause any appreciable loss in a well-constructed compressor. It is to be noted, however, that leakage will reduce the apparent work of compression, as calculated from the cylinder capacity, and hence will give a higher apparent efficiency—although the real efficiency is less. The loss due to clearance is almost wholly a loss of capacity. It must, of course, be taken into account when the work of compression is calculated from the cylinder capacity. The loss of capacity due to clearance may be conveniently included with the loss due to throttling during admission, the total volumetric efficiency being represented by the ratio of K E to the whole length of the diagram.

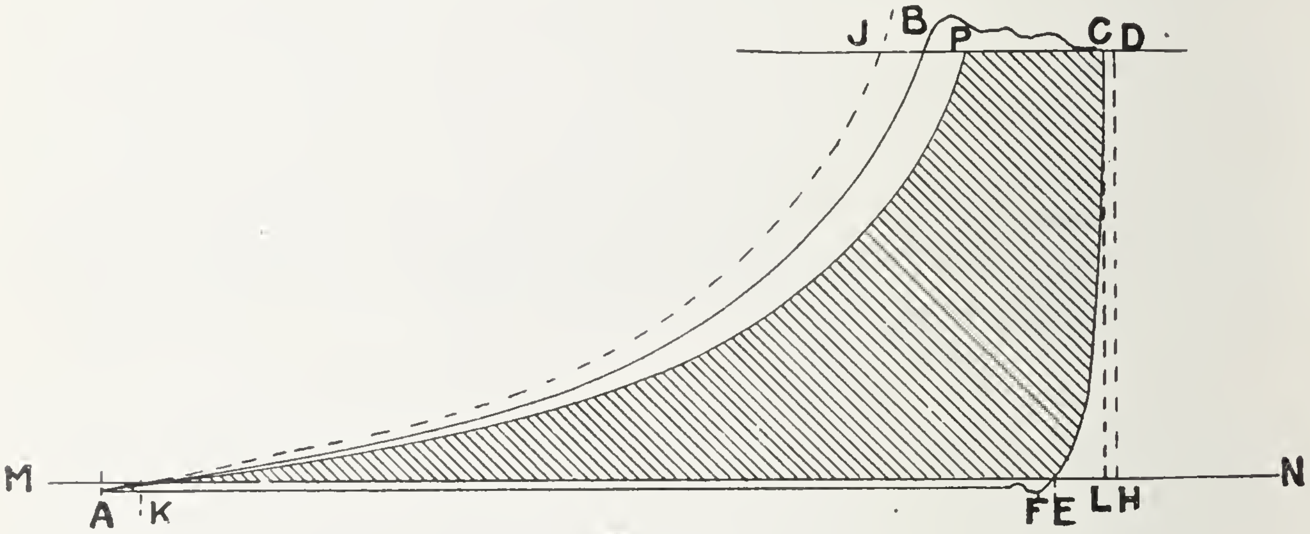


FIG.17

The loss due to the high temperature of the air in the cylinder at the beginning of the compression stroke may, as previously indicated, be of considerable importance. This loss may be made small by taking the air from as cool a place as possible and by exposing it as little as possible to hot surfaces during admission. A point just below the eaves on the north side of the building is generally a good place from which to draw the air. The pipe conveying the air to the compressor should preferably be of wood, brick or earthenware, in order to be non-conducting. The inlet valve passages should be short and direct, and the openings should have a large area compared to the area of metal next to them, so that only a small portion of the air may come in contact with the hot metal. Keeping the walls of the cylinder cool will help to prevent the air which has entered the cylinder from becoming heated before compression begins. This loss is not shown by the indicator cards and hence is often neglected. It could be determined by measuring the quantity of air compressed. Where this is not possible we should at least make some reasonable allowance for it, basing our judgment on any actual results obtainable, modified by the conditions in the given compressor. The largest loss included under E_c, that due to the rise of temperature during compression, is discussed under the head of *Removing the Heat of Compression.* Equations (10), (11) and (12) give the theoretical efficiency of adiabatic compression, where this loss is the only one included. We may determine this loss separately, if we wish, by calculating the exponent of the compression curve on the indicator card and inserting the value of n in equation (10).

To sum up, we may say that the total efficiency of the compressor, $E_m E_c$, is made up of two factors, the *mechanical efficiency* E_m, represented by the ratio of the indicated work on the air piston to the indicated work on the steam piston, and the *efficiency of compression* E_c, represented by the ratio of the isothermal work of compression to the indicated work on the air piston, both quantities being calculated for the same *mass* of air. This mass may be a pound of air or it may be the mass of a cubic foot of air under given conditions of temperature and pressure. When the actual work of compression per cubic foot of *free* air is calculated on the assumption that a cylinderful of free air is compressed per stroke, then the resulting efficiency must be multiplied by the *volumetric* efficiency of the compressor and by the efficiency represented by the ratio of the absolute temperature of the free air to the absolute temperature of the cylinderful of air. The product of these three factors will then be E_c.

Not many complete and reliable tests of air compressors have been made in this country, so that the figures given below refer chiefly to European compressors.

Prof. Unwin gives the two following tables. The figures are of special interest as showing the marked improvements which have been made in compressors. The compressor used at the St. Gothard tunnel in 1872 is interesting historically, as it was then that Prof. Colladon first introduced spray injection. It is to be remembered that E_m represents the mechanical efficiency, E_c the ratio of the useful work to the actual work of compression, and $E_m\ E_c$ represents the total efficiency.

Type of compressor.	p_1 atmos.	Lost work in % of useful work.	E_c
Colladon, St. Gothard	6	105.0	0.448
" "	6	92.0	0.521
Sturgeon	3	94.3	0.515
Colladon......................	4	38.15	0.722
Slide valve compressor..........	5	49.3	0.670
Paxman	..	42.7	0.701
Cockerill	6	40.2	0.713
Riedler—two-stage..............	6	12.07	0.892

Other and more extended experiments gave the following results :—

Compressor.	Steam work per hr., ft. pds.	Wt. of air compress'd.	Steam work per lb. of air.	$E_m\ E_c$	E_m	E_c
Paxman (Sturgeon)	1,980,000	20.24	97,830	0.551	0.85	0.648
Cockerill (Dubois-Francois).....	1,980,000	22.94	86,340	0.624	0.85	0.735
Riedler (two-stage)	1,980,000	28.06	70,550	0.764	0.87	0.898

In a duplex *geared* steam driven compressor described in *Engineering* of 1894, the I. H. P. of one steam cylinder was 81, and the I. H. P. of the corresponding air cylinder was 69, giving $E_m = 85\%$. As all the power is transmitted through two crank shafts and a pair of gears, we should expect the friction to be large.

The *American Machinist* of April 23, 1896, gave a report of a test of a duplex, three-stage, high-pressure compressor for furnishing compressed air at 2,000 pounds pressure for a pneumatic gun battery. Fig. 29 shows the general arrangement of this compressor. The mechanical efficiency, E_m, was 81.5%. The efficiency of compression, E_c, was 78.9%. This gives for the efficiency of the whole machine $81.5 \times 78.9 = 64.4\%$. The theoretical value of E_3 for three-stage adiabatic compression is 78.1%, so that the efficiency of compression came very close to the theoretical value, the loss from imperfect valve action being somewhat more than made up by the cooling effected by the jackets. The efficiency of single stage adiabatic compression to 2,000 pounds is only 45%. Both of these efficiencies are remarkably good, considering the extremely high pressure, and indeed the total efficiency of 64.4% is probably as high as in many compressors which compress to 100 pounds instead of 2,000 pounds.

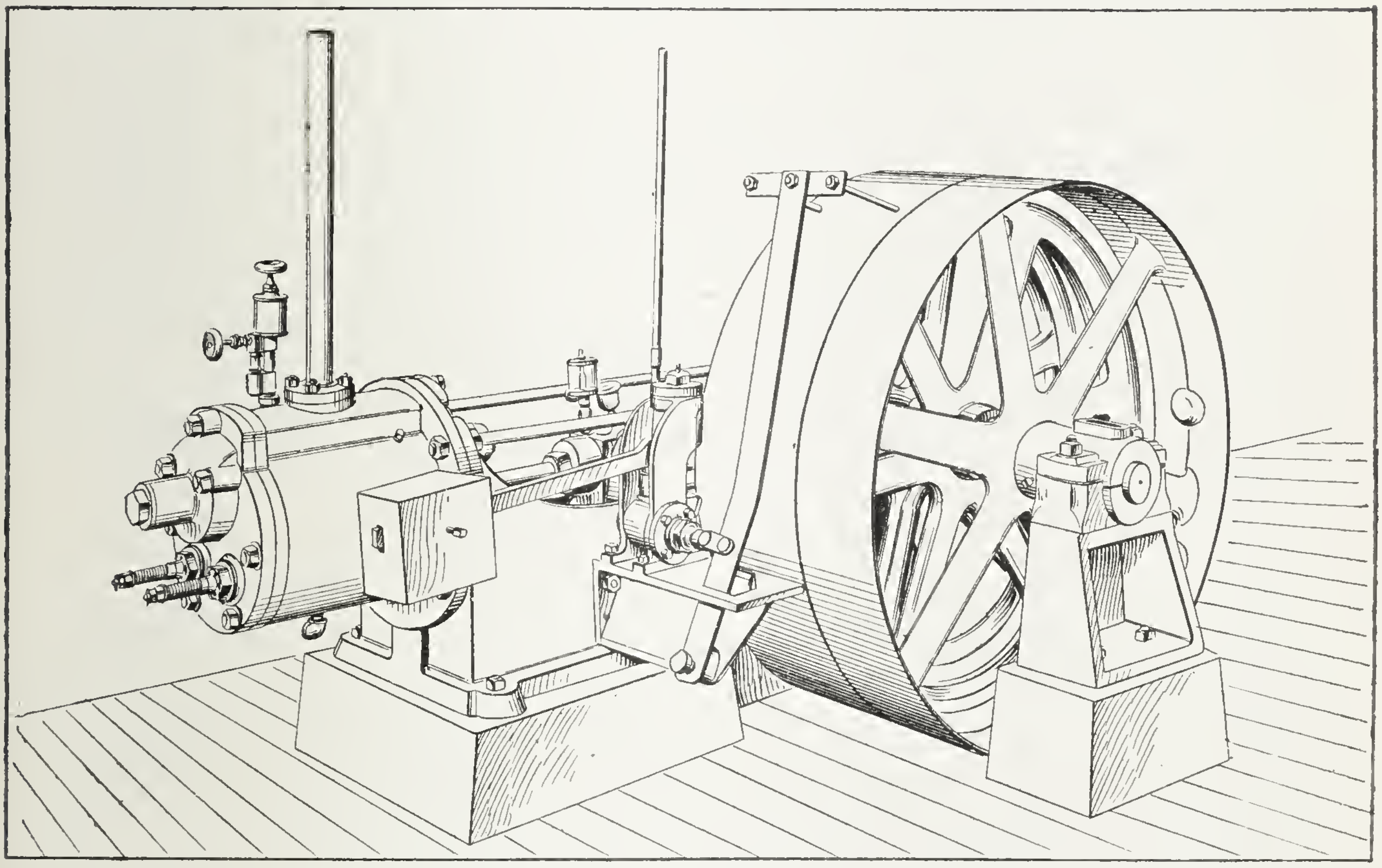


Fig. 18.

The mechanical efficiency of some kinds of " dry " air compressors is very high. It is stated that tests made by Professor Jacobus for the World's Fair judges showed a friction loss in a 300 horse-power compressor of less than five per cent.

There is still another efficiency which, while it cannot properly be said to pertain to the compressor, is of much greater practical importance. This is the efficiency of the steam end of the compressor. Many of the smaller compressors have common slide valves without cut-off, and even with good boilers and piping it is not to be expected that they will require less than six pounds of coal per horse-power-hour. Even in those compressors which have a Meyer cut-off with hand-adjustment, the steam cards are not such as to lead one to expect a very good steam economy; and they would probably require from three to four pounds of coal per horse-power-hour. Builders will furnish compressors of what Mr. Frank Richards calls the "five-C type," the Corliss Cross Compound Condensing Compressors, and guarantee that the coal consumption shall not exceed two pounds per horse-power-hour. With the two-stage Riedler compressors, driven by triple expansion engines, which are used in Paris, the net fuel consumption during a test was 1.3 pounds per I. H. P. per hour.

In compressing to 80 pounds gauge the efficiency of adiabatic compression E_1, is over 75%; that is, there is a possible loss of less than 30% of the work of isothermal compression, due to the heating of the air. As the worst compressor could not compress adiabatically, and the best could not compress isothermally, the possible loss by inefficiently cooling the air is small, compared with the possible 200 or 300 per cent. of excessive fuel consumption, caused by the inefficient use of steam.

EQUALIZATION OF POWER AND EFFORT.

In a steam-driven compressor, the power will evidently be applied most directly when the steam and air pistons are on the same piston-rod, as shown in Figs. 4, 13 and 14. This results, however, in a combination in which the effort of the steam is greatest at the beginning of the stroke, at the time when the resistance of the air is almost nothing; while at the end of the stroke, when the expansion has greatly reduced the steam pressure, the air pressure is a maximum. To make matters worse, the cushion due to clearance in the air cylinder acts *with* the steam at the beginning of the stroke.

Various methods have been employed for equalizing the effort of the steam and the resistance of the air throughout the stroke.

Early Designs.—In many of the older compressors the power was applied through a crank shaft, the cylinders and cranks being set at various angles, as shown in Figs. 5, 6, 7 and 8, taken from W. L. Saunders' paper on Compressed Air Production. Fig. 5 shows the Rand and Waring; Fig. 6 the Davies; Fig. 7 the Frick, and Fig. 8 the Burleigh, old Ingersoll and De La Vergne designs. About the only remaining representative of the class in which the cylinders are set at an angle to one another is the De La Vergne refrigerating machine. It has a horizontal steam cylinder and two vertical compression cylinders. The connecting-rods of the steam cylinder and one compression cylinder are attached to the same crank. The crank for the other compression cylinder is on the same crank shaft, but at an angle of about 150° to the first one.

These angular positions involve expensive construction and unsteadiness. The indirect application of the power also causes a greater loss in friction.

Air Brake Pump.—In the Westinghouse Air Brake Pump shown in Fig. 4, the forces are equalized in a most ingenious manner. This is a direct-acting or straight-line compressor; that is, the two pistons are on the same piston-rod. Both cylinders are double-acting. As will be seen by the indicator diagrams, shown in Fig. 23, the steam is throttled at the beginning of the stroke, but the pressure rises during the stroke till at the end the steam is at full boiler pressure. At the beginning of the return stroke the back pressure is very high, but falls off during the stroke. The high back pressure at the beginning of the stroke is made necessary by the cushion of compressed air in the clearance of the air cylinder. It will be evident that this arrangement is even more wasteful of steam than that of using steam at boiler pressure for full stroke; but, as previously noted, there are other conditions which make the question of steam economy a minor consideration.

Straight Line Compressors.—There is, however, no very great difficulty in getting nearly uniform motion at the fly-wheel of a straight-line compressor of the crank and fly-wheel type, shown in Figs. 13 and 14. It is only necessary to have a heavy fly-wheel and heavy reciprocating parts. Then at the beginning of the stroke, when the steam is at full pressure, its energy will be spent chiefly in accelerating the heavy reciprocating parts, while towards the end of the stroke, when the power of the steam is diminished, these reciprocating parts will give out energy while being brought to rest. The heavy fly-wheel will greatly assist in obtaining a uniform motion, but as the transmission of energy to and from the fly-wheel causes a pressure of the cross-head against its slide, of the wrist-pin and crank-pin against their bearings and of the crank shaft against its bearings, it is evident that the less work the fly-wheel has to do the less work will be lost in friction. If we can arrange so that the fly-wheel will have but little work to do to steady the motion, we shall be able to make it lighter, which will also diminish the friction. On the other hand, the transmission of energy from the steam to the reciprocating parts, and from them to the air, is direct and does not cause any side thrust. The fact that a great part of the power is thus transmitted directly, instead of through a crank and crank-shaft, explains why it is that the friction of both steam and air ends of an air compressor is less than the friction of an ordinary steam engine.

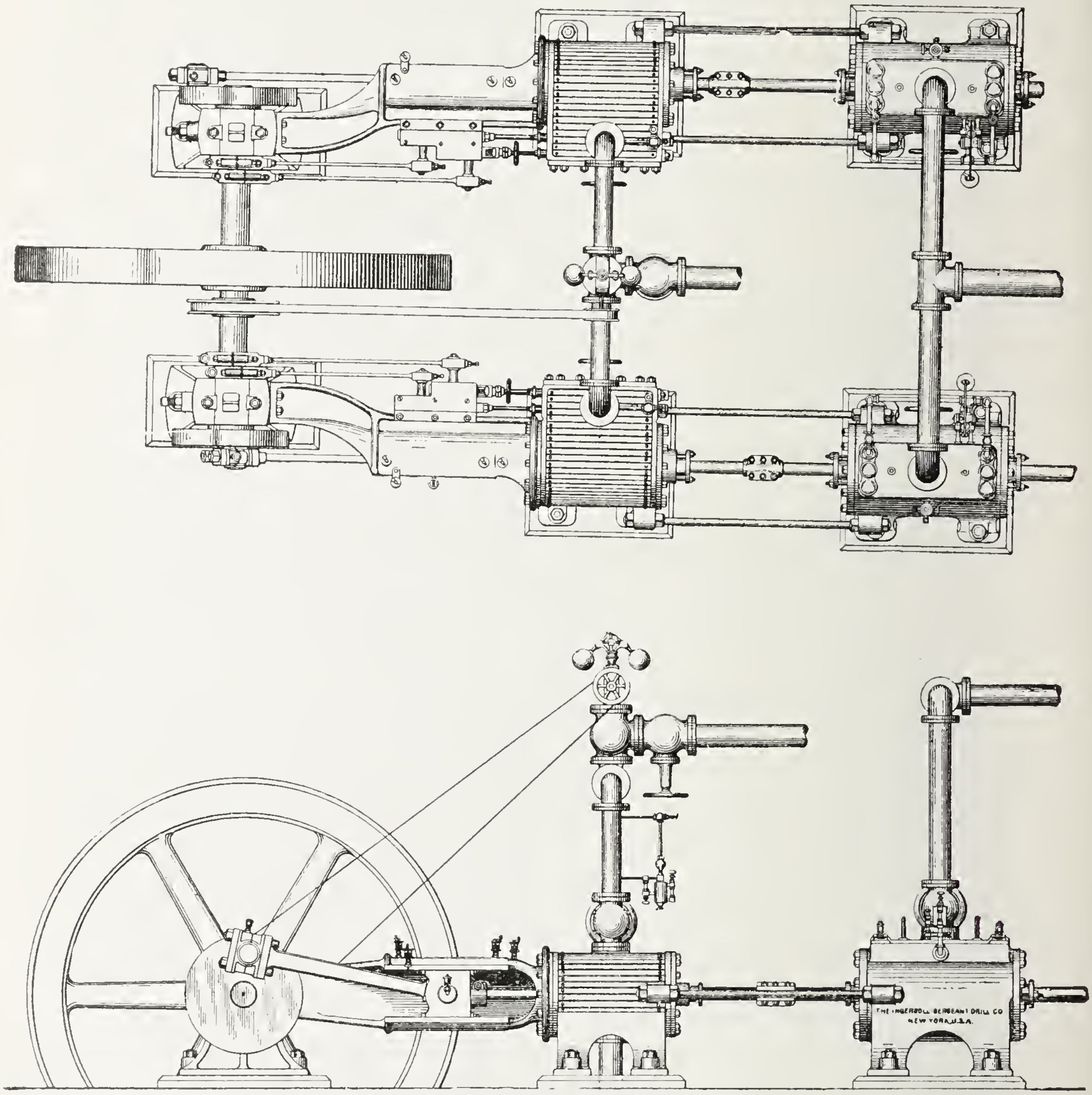


FIG. 19.

There are two methods which we may use in determining the weight and velocity of the reciprocating parts necessary to give nearly uniform motion at the fly-wheel. Let us suppose the form of the steam and air indicator-cards to be known. From these we can determine the unbalanced force for any point of the stroke. This should, after allowing for friction, be equal to the product of the mass of the reciprocating parts and their acceleration due to the uniform motion of the fly-wheel. This product may be called the rate of change of momentum of these parts. Of course we can only equalize these for one point of the stroke, preferably for a point near the beginning or end of the stroke. We may increase the product of the mass and the acceleration by making the reciprocating parts heavier or by increasing the speed of the compressor. By increasing the speed we soon reach the greatest piston speed that is desirable. We may, however, increase the acceleration while keeping the piston speed constant, by shortening the stroke and increasing the angular velocity. The large angular velocity will also enable us to reduce the size of the fly-wheel.

Another way in which we may look at the question is this : The difference between the work done by the steam and the work done on the air up to any point of the stroke, should, after allowing for friction, be equal to the energy of the reciprocating parts at that point, due to the motion derived from the uniform motion of the fly-wheel. In this case as well we can only make these equal for one point in the stroke. We should probably choose a point near the centre of the stroke, where the energy of the reciprocating parts is a maximum. We can increase the energy at the centre of the stroke by making the reciprocating parts heavier, or by increasing the piston speed. Changing the length of stroke while keeping the piston speed constant, will have no effect on the energy at mid-stroke.

As we get somewhat different conditions for maximum by these two methods, it might be possible to equalize for two points in the stroke ; that is, we might be able to make the unbalanced force, at the beginning or at the end of the stroke, equal to the rate of change of momentum at that point, and also make the excess work up to mid-stroke equal to the energy of the reciprocating parts at that point, the energy and the rate of change of momentum being both calculated from an assumed uniform motion at the fly-wheel.

As the unbalanced force at the beginning of the stroke and the excess work of the steam up to mid-stroke are both large, we are evidently driven to conclude that heavy reciprocating parts, high

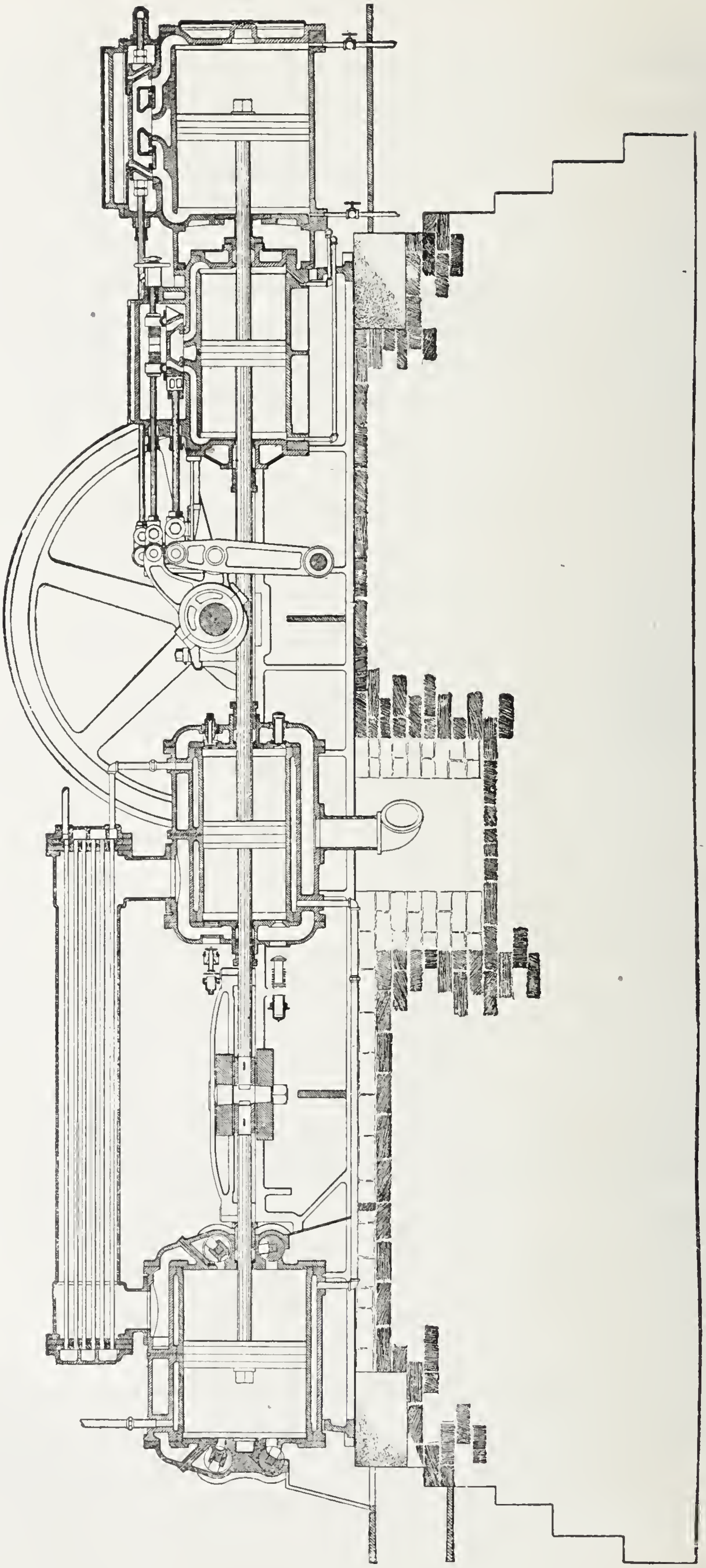


FIG. 20.

piston-speed and short stroke are desirable. The high linear and angular velocities have the further advantages of allowing a smaller fly-wheel, of increasing the capacity of a compressor of given size, of decreasing the relative friction loss, and, up to a certain point, of increasing the economy of steam.

When, however, we consider the loss during compression due to the heating of the air, we see that a slow speed and a long stroke would be the most favorable condition for the removal of heat from the air. The long stroke will also make the loss of capacity due to clearance relatively less.

Duplex Compressors.—Another principle which is used in equalizing the effort of the steam to the resistance of the air, in order to secure uniform motion, is shown in the duplex compressor (See Figs. 11, 19, 22, 27, 36). This consists practically in two straight-line compressors connected to the same crank shaft. The angle at which the cranks are set is usually, though not always, a right angle. Fig. 15 will serve to illustrate the action of duplex compressors. Suppose all four pistons to be moving toward the right, then the steam in the upper steam cylinder, being at full pressure, is furnishing power to compress the air in the lower air cylinder, the upper air cylinder requiring but little power during that time, and the lower steam cylinder furnishing but little. This will continue till the lower pistons reach the end of their stroke to the right and start back toward the left, when the conditions will be reversed. If the effect of the reciprocating parts is small there will evidently be considerable energy transmitted through the connecting-rods, cranks and crank-shafts—causing pressure on the bearings and great strains in the crank-shaft. The result is that the crank-shaft must be large and that the friction will be excessive.

It is evident, however, that the power may be equalized in each half of the duplex compressor by the same method as in a straight line compressor. We shall then have the practical advantages of duplex construction without the excessive friction and great strains. The advantages referred to are as follows:—With the cranks set as they usually are, there is no dead centre. Each half of the compressor being complete in itself, one half may be installed or run without the other. Finally, a smaller fly-wheel may be used with a duplex compressor than with a straight line compressor under similar conditions, or with a fly-wheel of the same size the motion will be steadier.

Compound Compressors.—The maximum force in a compressor due to the resistance of the air may be considerably reduced by compounding, that is, by compressing the air in two or more stages. The ideal diagram of two-stage compression is shown in Fig. 2. The actual diagrams are considerably different, owing to valve resistance, clearance, and the limited capacity of the intercooler.

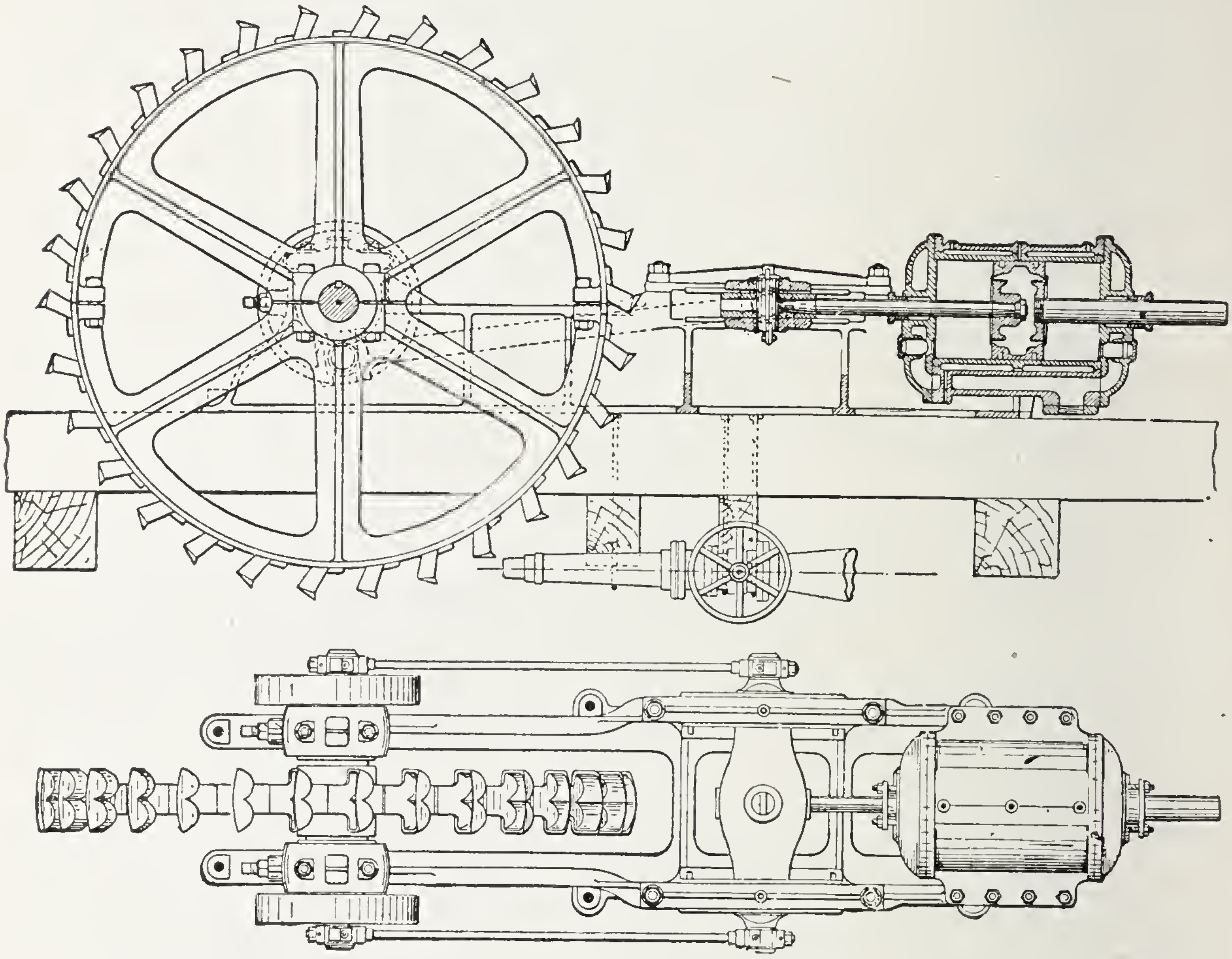


FIG. 21.

The condition for maximum efficiency under the ideal conditions was found to be $p_c = \sqrt{p_1 p_a}$ where p_a is the initial pressure, p_1 the final pressure and p_c the pressure in the intercooler. For this condition the capacity of the H. P. cylinder should be $\frac{p_a}{p_c}$ of the capacity of the L. P. cylinder.

When compressing to 100 pounds gauge, or 114.7 pounds absolute,

$$p_c = \sqrt{14.7 \times 114.7} = 41.1 \text{ pounds absolute}$$
$$= 26.4 \text{ pounds gauge.}$$

Then the capacity of the H. P. cylinder should be $\frac{14.7}{41.1} = .36$ of the capacity of the L. P. cylinder. These figures represent average practice fairly well. The pressure in the intercooler is usually higher than 26.4 pounds, but this may be explained by the fact that the intercooler is often too small and does not reduce the temperature within 100° of the initial temperature.

Let us make some simple assumptions, which will enable the calculations to be made readily and with sufficient accuracy for the present purpose. Let us take the case of two-stage adiabatic compression to 100 pounds gauge, very large intercooler where the air is cooled to the initial temperature (say 60° F.), most efficient size of H. P. cylinder, same stroke for both pistons, clearance and valve resistance negligible. To be definite, suppose the area of the L. P. piston to be 100 square inches (corresponding to a diameter of 11.28 inches) and its stroke 17.28 inches. The capacity of the compressor, which depends solely on the capacity of the L. P. cylinder, will then be one cubic foot per stroke. The area of the H. P. cylinder will then be 36 square inches and its capacity 0.36 of a cubic foot.

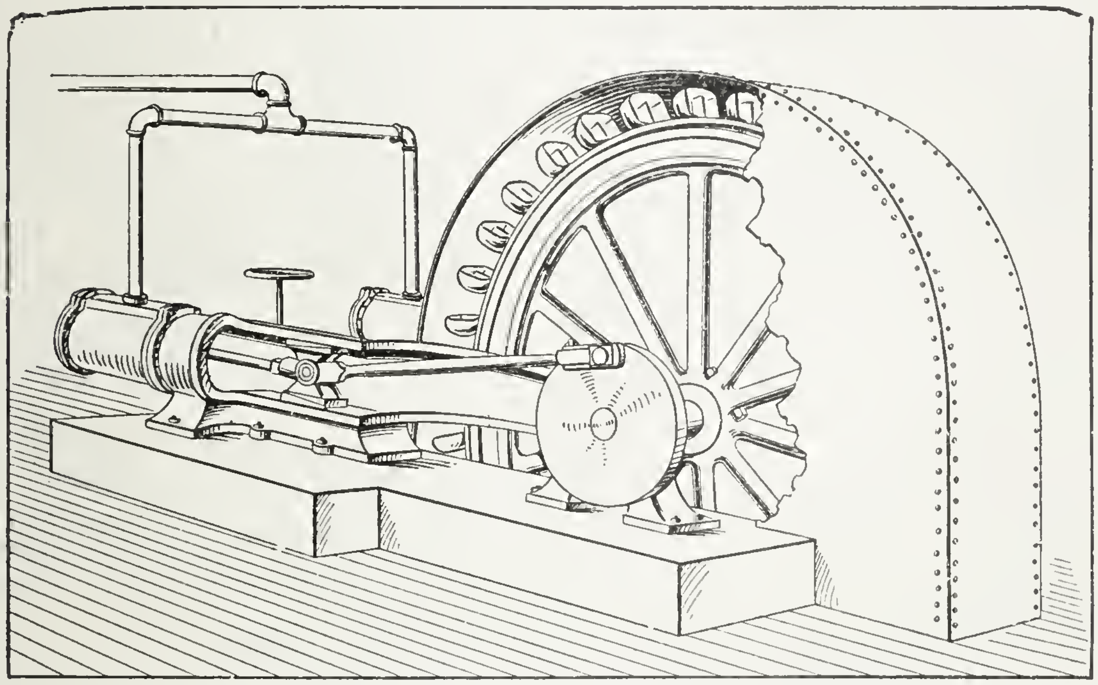


FIG. 22.

The maximum strains and the work of alternate strokes will depend on the arrangement of cylinders and pistons. The three different arrangements in common use are the single-acting tandem, the double-acting tandem, and the double-acting cross compound.

The single-acting tandem compound arrangement is shown in Fig. 24.

The action is as follows: Air is admitted to the large cylinder through the hole A and the inlet valve B, situated in the piston C. On the stroke to the left this air is compressed and forced out through the valve D, through the pipe E, into the space F. At the same time air from this space is being drawn into the high pressure cylinder through valve G. On the stroke to the right the air in the H. P. cylinder is compressed and forced out through valve K. During the stroke to the right air is also being drawn into the L. P. cylinder through valve B. Each stroke is thus an admission stroke for one cylinder and a compression stroke for the other.

Let us first find the maximum resistance due to the air pressure. At the end of the stroke to the right the air pressure on the large piston is balanced, there being air at atmospheric pressure on both sides. The small piston has air at atmospheric pressure on one side and air at 100 pounds gauge pressure on the other. The unbalanced force due to the air pressure is therefore 3,600 pounds. At the end of the stroke to the left the unbalanced pressure on the large piston is 26.4 pounds per square inch or 2,640 pounds in all, while the unbalanced pressure on the small piston is also 26.4 pounds per square inch or 950 pounds in all. This force acts in the opposite direction to the force on the large piston, so that the resultant force due to the air pressure is $2,640 - 950 = 1,690$ pounds. If the compression had been carried out in a single cylinder the terminal resistance would have been $100 \times 100 = 10,000$ pounds, so that the maximum strain in a single-acting tandem compound compressor under the assumed conditions is only 36% of that in a single-stage compressor.

Let us, for the sake of convenience, call the stroke to the right the admission stroke and the stroke to the left the compression stroke (thinking of the *large* cylinder). The terminal resistance for the admission stroke is 3,600 pounds, while for the compression stroke it is only 1,690 pounds, not half as much. Now, the acceleration of reciprocating parts, due to a uniform motion of the fly-wheel, will be nearly the same at the ends of both strokes, and for economical working the steam pressure must be nearly the same in both cases, so that it would be practically impossible to equalize the forces so as to secure approximately uniform motion.

If the compressor is delivering air at some pressure other than 100 pounds per square inch, then the conditions will be as follows:— The diagram of the L. P. cylinder will remain unchanged, the pressure in the intercooler will be the same, the quantity of free air com-

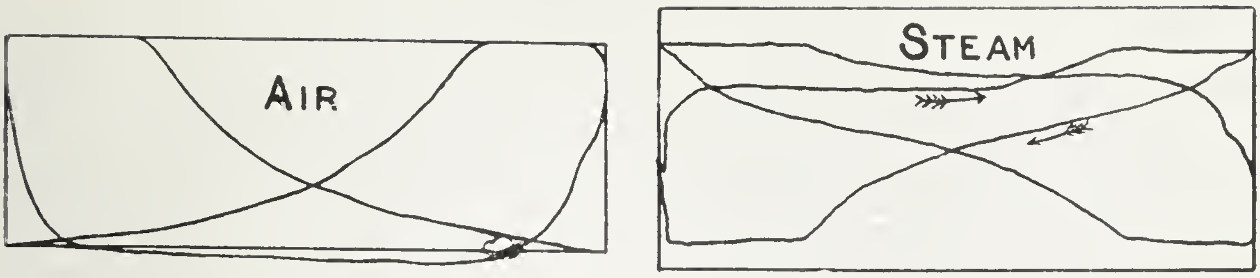


FIG. 23

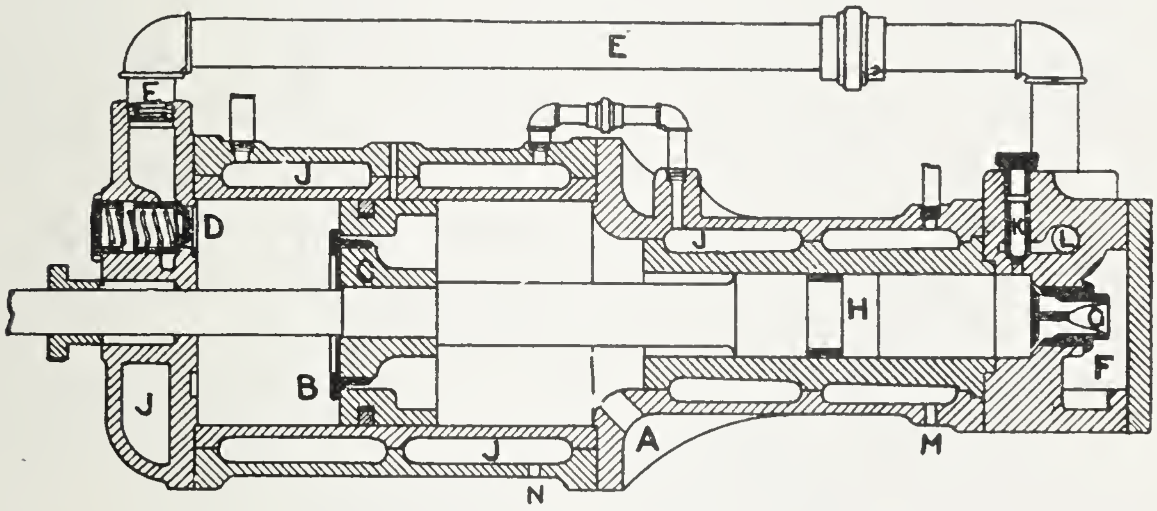


FIG. 24

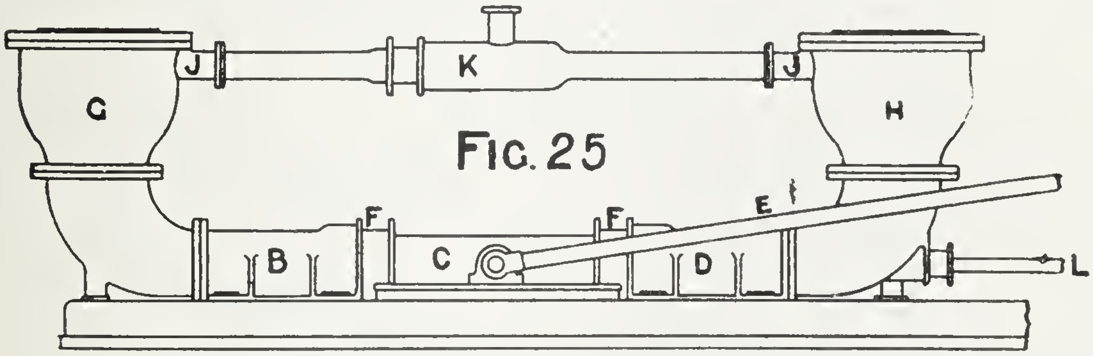


FIG. 25

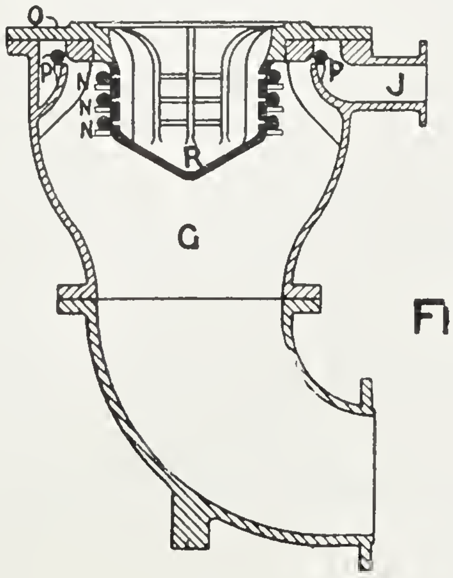


FIG. 26

pressed will be the same, the admission line of the diagram of the H. P. cylinder will be the same, and resultant force of the air on both pistons will be the same for the compression stroke. Besides the pressure of the air delivered, the only thing changed will be the compression line of the H. P. cylinder, which indicates the effort of the piston on the air for that stroke. If the pressure of the air delivered were 47 pounds instead of 100, then the terminal resistance of the alternate strokes would be equal, but even then the work of the admission stroke would be greater than that of the compression stroke, and moreover the compounding would then be inefficient.

Let us next consider the work of alternate strokes. From equation (1*a*) we can get the mean effective pressure for each cylinder.

L. P. cylinder M. E. P. $= 3.45 \times 14.7 \left[\left(\frac{41.1}{14.7}\right)^{0.29} - 1\right] = 17.6$

H. P. cylinder M. E. P. $= 3.45 \times 41.1 \left[\left(\frac{114.7}{41.1}\right)^{0.29} - 1\right] = 49.2$

Adding the back pressure (above the atmospheric pressure) to each of these, we get the M. E. P. of the compression stroke only to be

Comp. stroke of L. P. cyl. — M.E.P. = ...17.6 pds. per sq. in.
" " H.P. cyl. — M.E.P. = 49.2 + 26.4 = 75.6 pds. per sq. in.

We then have the work of the several strokes as follows:—

L.P. cylinder ad. stroke = ... 0 ft. pounds.
comp. stroke = 17.6 × 100 × 1.44 = 2,534 "
H.P. cylinder ad. stroke = ... 26.4 × 36 × 1.44 = 1,369 "
comp. stroke = 75.6 × 36 × 1.44 = 3,921 "

Since the admission stroke of the L. P. cylinder corresponds to the compression stroke of the H. P. cylinder, and *vice versa*, we have:

Total work of admission stroke = 3,921 foot pounds.
" " compression " =
2534—1369 = 1,165 " "

Hence, in this case the work of the admission stroke is over three times as great as that of the compression stroke. Let us examine the case where the air is not compressed at all in the second cylinder, but is delivered at 26.4 pounds pressure. We will then have:

Work of admission stroke = 1,369 foot pounds.
Work of compression " = 1,165 "

Even in this extreme case the work of the admission stroke is the greater.

We are driven to the conclusion that the two-stage, single-acting tandem arrangement is a very poor one as regards the equalization of power or effort.

The next compound arrangement to be considered is the double-acting tandem. Fig. 20 shows a section of a Norwalk two-stage, double-acting tandem compressor, driven by a tandem compound steam engine. The action will be readily understood from the figure. After compression in the L. P. cylinder on the left, the air flows through the intercooler to the H. P. cylinder. The compressed air from the H. P. cylinder flows through the large pipe shown below the cylinder.

The work of alternate strokes and the resistance at corresponding parts in the alternate strokes are evidently equal, so that it will only be necessary to compare this case with the single-stage, double-acting compressor. The terminal resistance of each stroke will be the sum of the terminal resistances in the previous case, or 3,600 + 1,690 = 5,290 pounds. If the compression all took place in the large cylinder the terminal resistance would be 10,000 pounds, nearly twice as great. The work per stroke will be the same as in the cross-compound compressor to be considered next.

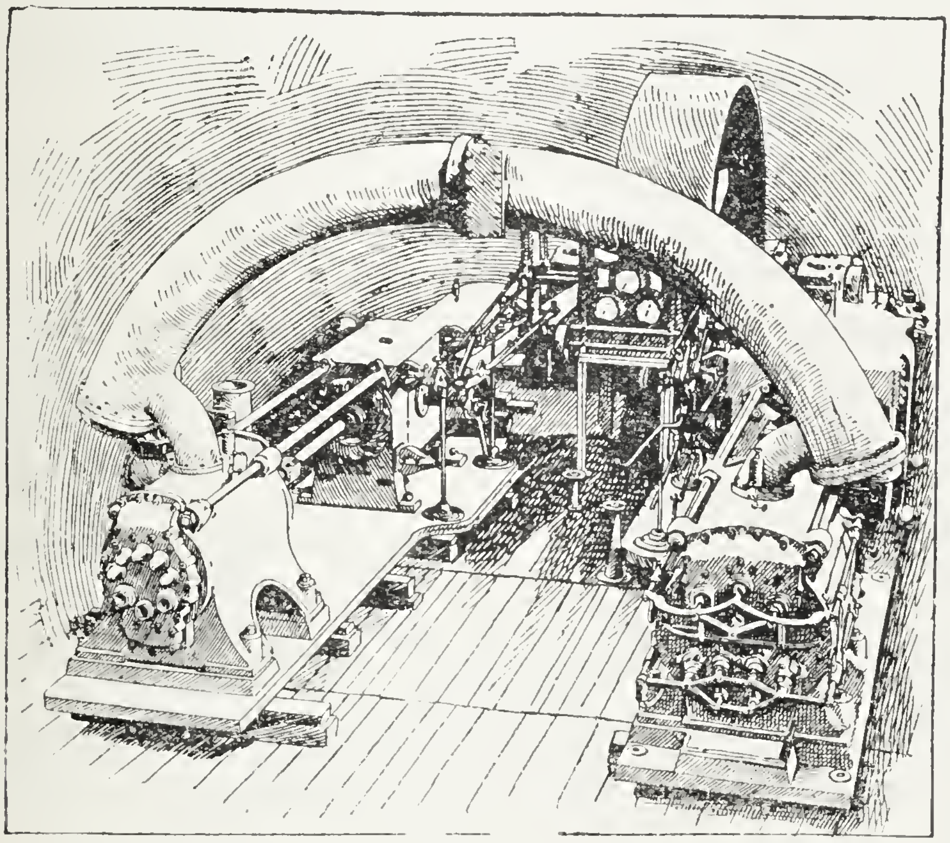


FIG. 27.

The third arrangement of compound compressors is the double-acting cross compound. Fig. 28 shows the general arrangement of a duplex cross compound compressor, driven by a cross compound engine. L A and H A are the low pressure and high pressure air cylinders, L S and H S the low pressure and high pressure steam cylinders. C represents the intercooler and R the receiver, through which the air passes before entering the distributing pipes. The dotted lines indicate the path of the air through the machine. Fig. 27 shows a compressor of this design, as built by the Canadian Rand Drill Company.

The terminal resistance of the air in the low pressure cylinder L A is (in our assumed case) 26.4 x 100 = 2,640 pounds. The terminal resistance of the air in the high pressure cylinder H A is (100 – 26.4) × 36 = 2,650 pounds, practically the same. Either of them is but a little more than ½ of the corresponding terminal resistance of a duplex single-stage compressor of the same capacity.

From the mean effective pressures previously found we get the work per stroke for each cylinder, as follows :

L. P. cylinder = 17.6 × 100 × 1.44 = 2,534 foot pounds.
H. P. cylinder = 49.2 × 36 × 1.44 = 2,441 "

These also are practically the same.

We can see from our general equations that the terminal resistance and the work per stroke for each cylinder should be the same, in our assumed case. The ratio of the piston areas is $\frac{p_a}{p_c}$ but this equals $\frac{p_a}{\sqrt{p_a p_1}} = \frac{\sqrt{p_a p_1}}{p_1} = \frac{p_c}{p_1}$, that is, the areas are inversely as the terminal pressures, so that the terminal resistances are equal. Also, in calculating the work of compression from equation (6), there being the same weight of air in each case, the only difference is that we have $\frac{p^c}{p_a}$ for the L. P. cylinder, and $\frac{p_1}{p_c}$ for the H. P. cylinder. But $\frac{p_c}{p_a} = \frac{p_1}{p_c}$ so that the work per stroke is the same in each case.

In single stage adiabatic compression to 100 pounds gauge the lost work is 36.7% of the work of isothermal compression, while for two-stage adiabatic, with perfect intercooling, the lost work is 16.5% of the work of isothermal compression. Hence the maximum possible saving by two stage compression is about 20%. The saving practically possible is considerably less, for the following reasons :—(1) The intercooler does not usually reduce the air to the initial temperature. (2) Considerable saving over adiabatic compression can be affected in single-stage compression, hence there is not so much lost work to be

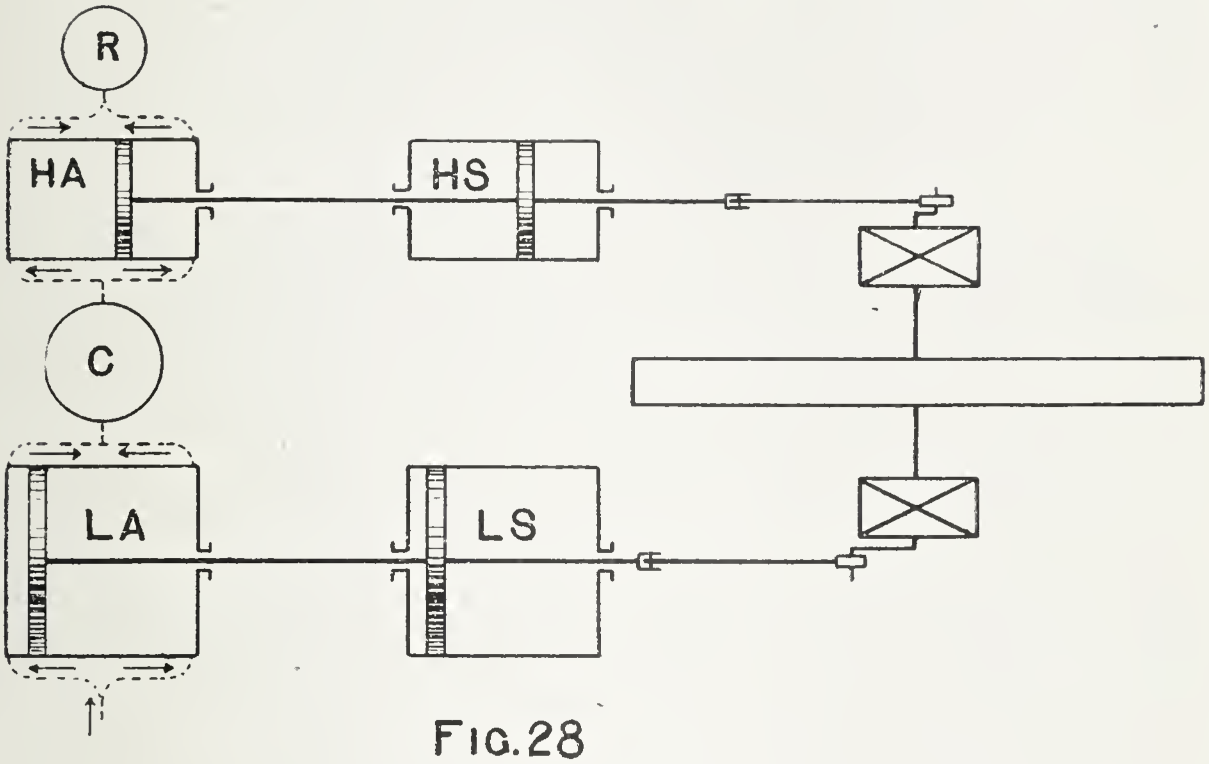


FIG. 28

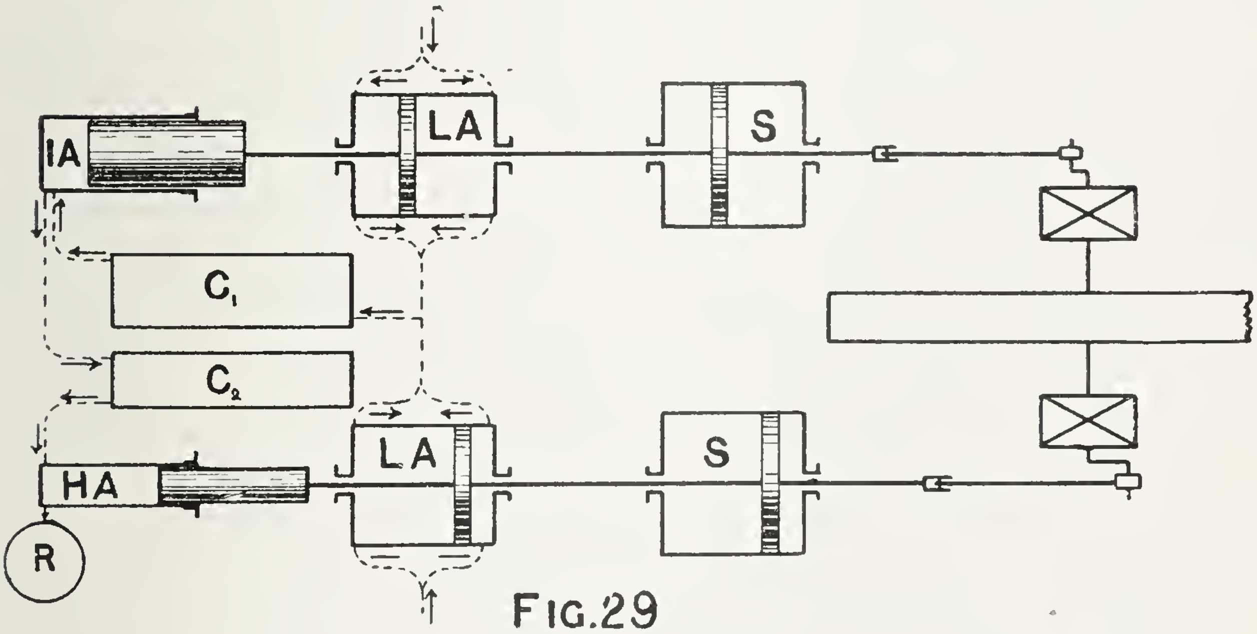


FIG. 29

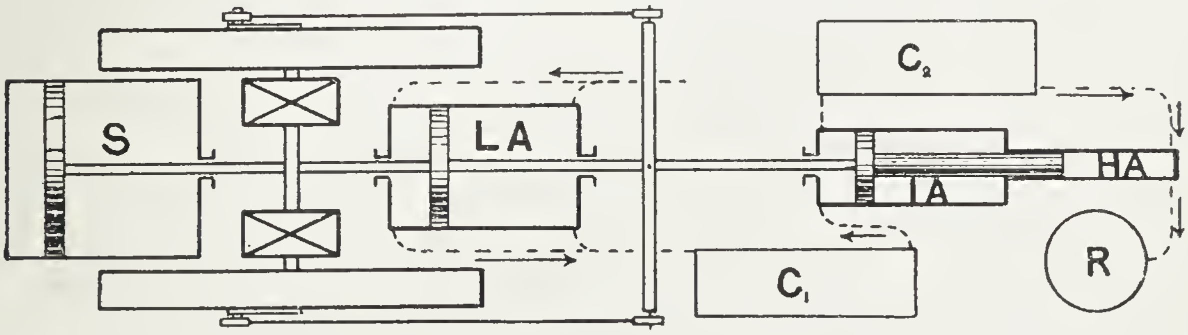


FIG. 30

saved by compounding. (3) The losses due to the extra valve resistance and extra friction, caused by the additional cylinder, will partly counteract the saving effected.

METHODS OF DRIVING.

The greater number of compressors in use are driven by steam, but there are also quite a number driven by water power, and a few driven by electric motors. According to the method of connecting to the driving power, the compressor may be classed as either belt-driven, geared or direct-connected.

In machine shops and other places where power can be conveniently taken by a belt from line shafting, some form of belt-driven compressor is in many respects most suitable, especially for small quantities of air or where the demand is irregular. They are very simple, and hence the first cost and the expenses for attendance and repairs are much lower than for an independent steam-driven compressor. A still more important advantage which may be claimed for them is that of economy of steam.

In the large railroad shops and other machine shops in which compressed air is used, the main engines are generally of a good Corliss type and are fairly economical. The average coal consumption might probably be taken as 2½ pounds per H.P. hour. A common steam-driven compressor of moderate size, with a plain slide value or a Meyer cut-off on the steam cylinder would require at least 4 pounds and probably 6 pounds of coal per H.P. hour. In addition to this, the irregular demand will necessitate considerable variations in the speed of the compressor, which is a condition very detrimental to steam economy. Hence we see that even after allowing for considerable losses of power in transmission by belting and shafting, the belt-driven compressor is more economical than the direct-connected steam-driven compressor, under the given conditions. The independent steam-driven compressor has one point of superiority in that it may be run whether the rest of the machinery is in operation or not. For large quantities of air the compressor engine may be made as economical as any other engine.

Fig. 18 shows a Rand belt-driven compressor with a belt-shifting regulator. This regulator operates by air pressure, being connected to the receiver by a pipe. When the pressure rises above a certain point the regulator shifts the belt over to the loose pulley. When the pressure falls a few pounds the belt is shifted back to the tight pulley and the compressor starts again. Fig. 10 shows a simple plan of the same machine, the regulator not being shown. For larger belt-driven machines the belt-shifting regulator cannot so well be employed. When necessary these may be unloaded by an automatic regulator, acting on the air valves. One type of straight line belt-driven compressors is like Fig. 21, but with a belt pulley in place of the Pelton wheel. The pulley is made heavy in order to act as a fly wheel as well. Another type of straight line belt-driven compressors has two belt pulleys, a crank between them and a single connecting rod. When this type is used for heavy duty two belts are employed to give a central pull on the crank. Fig. 11 shows the arrangement of a duplex belt-driven compressor. This type is more suitable than the straight line type for large quantities of air or high pressures, as the resistance is more evenly distributed throughout each revolution. Large compressors of this type are sometimes belted to a water wheel, such a combination allowing considerable latitude in the design of both water wheel and compressor.

For some purposes a connection by gearing is more suitable than belting. Gearing gives a more positive motion, gives a definite speed ratio, and is more suitable for transmitting a large force. Some electrically-driven compressors are geared, the pinion on the shaft of the electric motor meshing with a large gear which takes the place of the belt pulley on belted compressors. Large belt-driven compressors are sometimes made with a gear connection between the pulley-shaft and the crank-shaft. This permits the use of a smaller belt and gives a higher belt speed. The gearing ratio is usually two to one, the large gear being on the crank-shaft of the compressor. Water-power compressors are also sometimes geared, the pinion being on the turbine shaft, and the gear on the crank-shaft of the compressor. The writer knows of but one example of a compressor geared to a steam engine, and as there are a number of unique features about this compressor a short description of it will be given.

This compressor was built by the English firm of Arnold Goodwin & Son, Southwark, for a carpet-cleaning factory. It is a duplex compressor and consists practically of two engines with their cranks set at 90 degrees on one crank-shaft, and two compressors with their cranks set at 90 degrees on another crank-shaft, these two crank-shafts being connected by a pair of spur gears. The crank-shaft of the engines also carries a fly-wheel. The engines have cylinders 22 x 42 and are designed to run at 60 revolutions, giving a piston speed of 420 feet per minute. The compressors have cylinders 26 x 42 and run at half the speed of the engines, the gearing ratio being two to one. Both steam and air valves are different from the kinds in ordinary use on compressors. The steam valves are piston valves, moved by a cam on the crank-shaft. The valve rod is held up against the cam by an auxiliary steam cylinder. The cut-off is at one-tenth stroke. The inlet valves of the air cylinders are 21½ inches in diameter (the cylinders are 26 inches in diameter), and give an opening of 10% of the cylinder area. They are moved by the piston rods, which pass through the centres of the valves and open and close them at the turn of the stroke. The delivery valves are poppet valves, having a vertical lift, and are apparently without springs. Steam and air cards from this compressor are given in *Engineering* of Aug., 1894. An inspection of the air cards showed a considerably smaller volume of air for one cylinder than for the other, at the same pressures. A few measurements were taken and the following results obtained. There was very little throttling of the inlet, and yet the compression line did not leave the atmospheric line until about 10% of the stroke for one end (call it the head end) and 14% of the stroke for the crank end. It appears quite evident that the inlet valves close much too slowly. Taking the volume to the point where the compression line leaves the atmospheric line as the initial volume, the following results are obtained :

Pressure.	Vol. h. end.	Vol. c. end.	Vol. Iso.	Vol. Adia.
0	1.00	1.00	1.00	1.00
15	.60	.55	.50	.61
26	.45	.37	.35	.49
60	.26	.20	.20	.31
70 (Receiver P.)	.23	.18	.17	.29

There is no apparent reason for better cooling in one end of the cylinder than in the other, and even if there were, the compression line for the crank end lies nearer the isothermal than it is reasonable to expect from a simple water-jacketed cylinder. The most obvious conclusion is that the inlet valve for that end leaked.

The I.H.P. for one half was: steam cylinder 81 I.H.P., air cylinder 69 I.H.P., giving a mechanical efficiency of 85%. This is fairly high, considering that all the power is transmitted through two crank shafts and a pair of spur gears.

We have considered various arrangements of belted and of geared compressors. The third and by far the largest class comprises direct-connected compressors. The advantages of direct

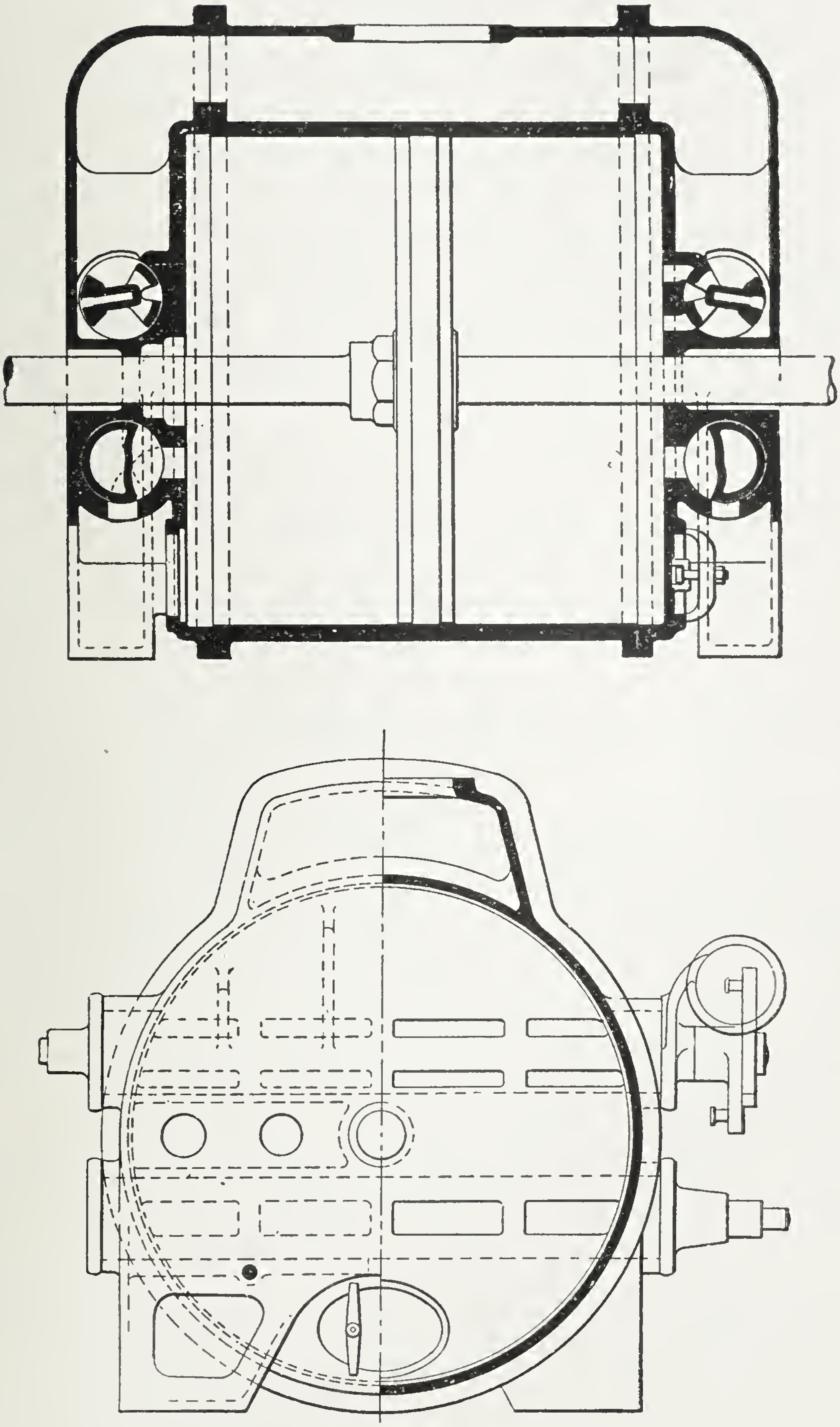


FIG. 31.

connection are simplicity, positive action and small friction losses. Direct-connected water power compressors (see Figs. 21 and 22) are, almost without exception, driven by Pelton wheels. This wheel is very simple and its form and its weight are such that it can be put in place of the belt pulley of a belted compressor and can furnish driving power and act as a fly-wheel as well. By choosing a suitable diameter of the wheel it is possible to have the best peripheral speed of the buckets for the given head and at the same time to have the best speed of rotation for the compressor. Fig. 21 shows an Ingersoll-Sergeant straight-line water-power compressor, and Fig. 22 shows a Rand duplex water-power compressor. The sheet iron casing around the Pelton wheel of the latter is merely to prevent the water from spraying over the machine.

We now come to the last and in many respects most important method of driving compressors, that of direct connection to a steam engine. Even if we do not include with them the 30,000 air-brake pumps used by the American railroads, the direct-connected steam-driven compressors probably still out-number all others. It has been previously pointed out that there is greater room for economy in the design of the steam end than in the design of the air end. Under ordinary conditions the greatest possible difference in the efficiency of compression between a poor compressor and the best compressor made is about 20 per cent., while the difference between the steam consumption per horse-power-hour of a common slide-valve engine and the best Corliss engine may be 200 or 300 per cent. of the latter quantity. It is natural then to make the description of the steam engine a most important part in the name of a compressor. For example, a compressor which is generally used to produce large quantities of compressed air at the lowest power cost is called the Duplex Cross Compound Condensing Corliss Compressor.

Figs. 13 and 14 show different arrangements of straight-line steam-driven compressors. Fig. 13 is a very common type. Fig. 37 shows the Rand compressor of this type. This arrangement makes a very compact machine, while at the same time giving a fairly long connecting rod. It is generally self-contained, so that little or no foundation is necessary. The cross-head is made to swivel at the centre so that no bending strain shall be brought on the piston-rod. In Figs. 20 and 21 there is shown a section of the cross-head at its point of connection to the piston rod, in which the pin of the swivel connection can be seen. The clearance can be adjusted by "taking up" the connecting rods or by moving the cross-head along the piston-rod.

Fig. 15 shows the most common arrangement of the principal parts of duplex single-stage compressors. From the figure it is evident that a duplex compressor has ample room for a large fly-wheel, though whether a large fly-wheel is an advantage may be questioned. This compressor can not very well be made self-contained by putting all the parts on a box bed, as in Figs. 18, 20, 21 and 36. The frame is usually of the girder type, or partly of the girder type, but with tie rods between the cylinders, as in Fig. 19, which shows the Ingersoll-Sergeant duplex. Fig. 16 shows another arrangement for duplex compressors. The Blake and Knowles and the Clayton are about the only compressors of this type. The Blake and Knowles compressor of this type is a small compact affair designed for " racking off" beer. Fig. 36 shows the standard design of the Clayton compressor. Both firms mount this type on a box bed, making it self-contained.

Fig. 12 is shown as one of the oddities in compressor design. It is one of the types of the English firm of Schram & Co. As all the power is transmitted through the crank shaft, there is likely to be a considerable friction loss.

We now come to compound compressors. Of these there are but two general types, the tandem compound straight line and the cross compound duplex.

The air cylinder of a single-acting tandem compound compressor is shown in Fig. 24. There is usually an intercooler instead of the simple pipe E between the cylinders. The general arrangement is like Fig. 13, but with the two air cylinders in place of the one shown in the figure.

Fig. 20 shows a straight-line double-acting tandem compound compressor driven by a tandem compound engine. The construction will be readily understood from the cut. The whole machine is mounted on a box bed and is self-contained. The advantages of the tandem compound arrangement lie chiefly in the direct application of the power, and in the great momentum of the reciprocating parts.

Fig. 28 shows the general arrangement of the cross compound duplex. This is the kind generally used for producing large quantities of compressed air at a low cost. The engines are usually fitted with Corliss valves and run condensing, making the " five C " type, the Corliss Cross Compound Condensing Compressor. Fig. 27 shows a compressor of this type built by the Canadian Rand Drill

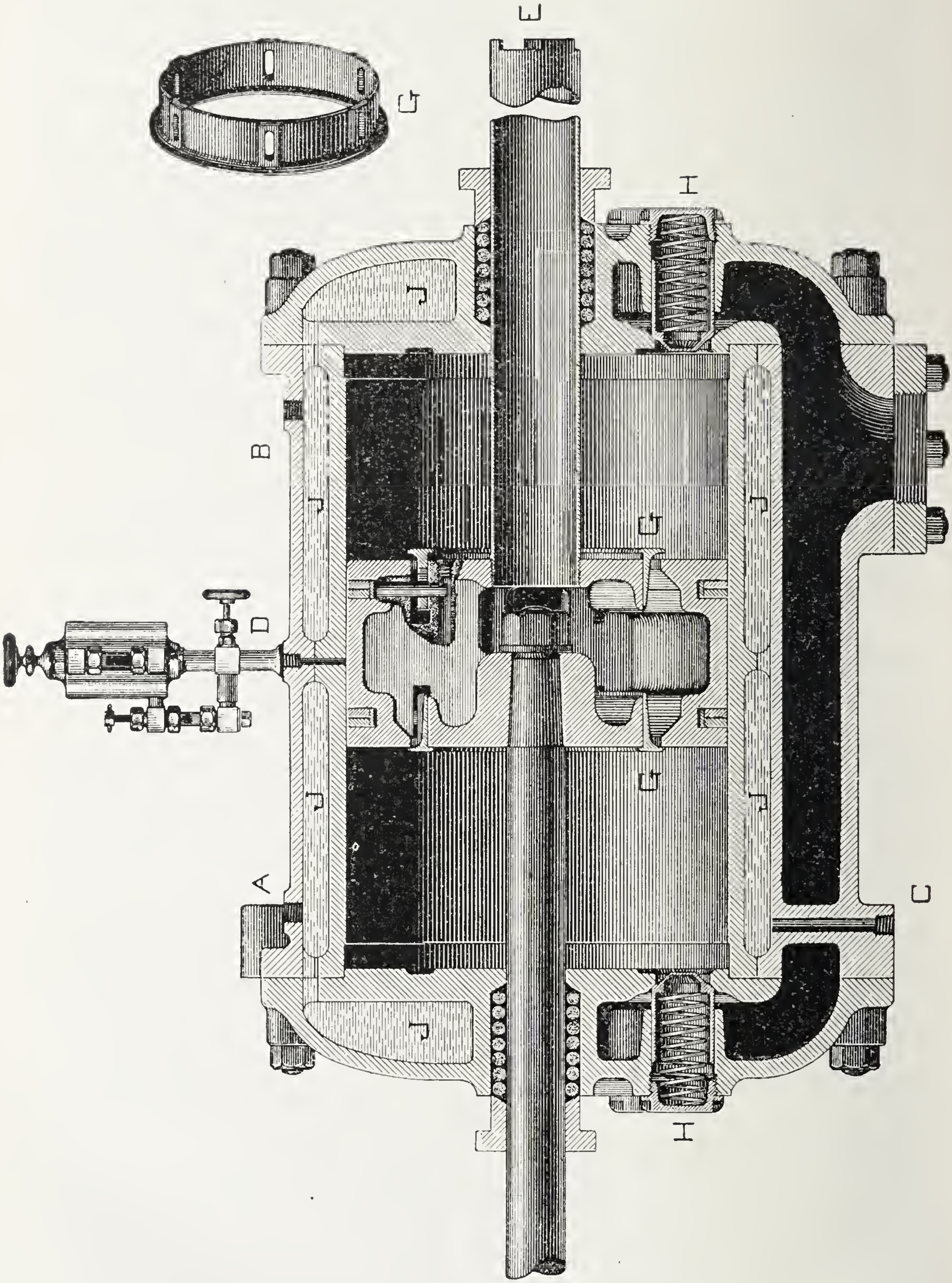


FIG. 32.

Co. The intercooler of this compressor is the arched pipe extending across from one cylinder to the other. This contains a large number of small tubes through which cold water flows.

Fig. 9 shows another odd English design. It is manufactured by the firm of S. H. Johnson & Co. It will be seen that it consists of a tandem compound steam engine driving a tandem compound compressor, but it differs from Fig. 20 in having the power transmitted through a crank shaft.

Fig. 30 shows the general design of the Norwalk straight-line three-stage compressor. The dotted lines show the direction of air circulation through the machine. The intercoolers C_1 and C_2, are simply diagrammatic, the actual intercoolers being on the top of the machine and extending nearly the whole length of it. It will be seen that the low pressure cylinder L A is double-acting, but that the intermediate cylinder I A, and the high pressure cylinder H A, are single-acting and compress on alternate strokes. This arrangement is open to somewhat the same objection as the single-acting tandem compound arrangement, shown in Fig. 24; that is to say, the resistance and the work of alternate strokes are not equal. In this case, though, owing to the low-pressure cylinder L A being double-acting, the proportional inequality will not be nearly so great, and is hardly worth considering when compared with the advantages of simplicity of construction, good cooling and ease of packing, secured by the single-acting arrangement. The Norwalk Co. kindly sent blue-prints and other matter relating to this compressor, from which the following description is compiled.

The steam cylinder S is 16 inches in diameter. The double-acting intake cylinder L A is 10½ inches in diameter, the single-acting intermediate air cylinder I A is 6¼ inches in diameter, and the single-acting high-pressure cylinder H A is 2⅝ inches in diameter. The common stroke is 16 inches. The clearance of L A is 3%, of I A it is 3.1%, and of H A it is 2.5%. This includes indicator pipes and rigging, which, in the case of the high-pressure cylinder, formed a considerable portion of the clearance. Blue prints of indicator cards show that the final gauge pressures were:

Low pressure air cylinder L A..........	72	pounds per square inch.
Intermediate air cylinder I A	410	" "
High pressure air cylinder H A	2,030	" "

Diagrams are given of the "Combined unbalanced pressures on the three air pistons, referred to the 10½ inch air piston." These show at a glance that the power and the effort of alternate strokes are not equal. A combined card for the three cylinders, with adiabatic and isothermal lines drawn, shows a very large gain over single-stage adiabatic compression.

Fig. 29 shows the usual design for three-stage duplex compressors. There are two double-acting steam cylinders, two double-acting low-pressure air cylinders, a single-acting intermediate air cylinder and a single-acting high pressure air cylinder. Considering one-half of this compressor by itself, it will be evident that the work and the resistance of alternate strokes are very unequal. On the forward stroke the pressure of the air in the single-acting cylinder assists the steam, on the return stroke it opposes it, hence there must, in any case, be considerable energy transmitted through the crank-shaft, either to and from the fly-wheel or from one side of the compressor to the other. Taking the compressor as a whole, the work of alternate strokes would be most nearly equalized when the cranks were set at 180°, but then of course there would be a possibility of the compressor getting on the dead centre.

In the *American Machinist* of April 23, 1896, and in the *Journal of Electricity* (San Francisco) for December, 1895, there were descriptions of two compressors of this type which were designed and built in San Francisco for the pneumatic gun battery at Fort Winfield Scott. These compressors, from the excellence of their design and construction and from the unusual conditions of the service, present many features of interest.

There are two exactly similar compressors in the plant, and the description applies to either one of them. The cranks are set at 145° in order that the machine may be as nearly balanced as possible and yet be able to start from any position. The steam cylinders are high-pressure, non-condensing. They are twenty inches in diameter by twenty-four inches stroke, and are fitted with Meyer hand-regulation cut-off. The steam pressure usually carried in the boilers is 100 pounds, and the engines ran under full load when cutting off at $\frac{3}{8}$ stroke. "The low-pressure air cylinders are placed next the steam cylinders. They are double-acting, with pistons packed in the usual manner, by cast-iron rings sprung into place. The intermediate and high-pressure air cylinders are single-acting, with plungers. The intermediate plunger is packed with soft packing in the ordinary form of stuffing box. The high-pressure plunger is packed with sectional babbitt and brass rings. This has proved a very satisfactory packing for high pressures. It does not leak when properly made and the friction is not excessive. The valves are all of the poppet type, carried in bronze casings."

The arrangements for cooling are very thorough. The air cylinders and heads are water-jacketed, and water circulates in the intermediate and high-pressure rams.

Between compressions and after the final compression the air passes through large intercoolers, situated in cement tanks the foundation of the machine.

The American Machinist gives the following as the result of a test :

The I.H.P. of the steam cylinders was 351.6 horse-power. This was at 100 revolutions per minute, or a piston speed of 400 feet per minute. The combined I.H.P. of the air cylinders was 286.7 horse-power. This gives a mechanical efficiency of 81.5%. The pressure of the discharge of each air cylinder, as shown by gauges, was as follows :

Low pressure	75	pounds
Intermediate	375	"
High	2,000	"

TEMPERATURES.

	Temperature of suction	Temperature of discharge	Temperature by adiabatic compression	Difference
Low pressure cylinder	75°	320°	444°	124°
Intermediate pressure cylinder.	73	289	355	66
High pressure cylinder	69	358	392	34

The final temperature of single-stage adiabatic compression to 2,000 pounds is 1,769 degrees.

These figures indicate the relative amounts of heat abstracted by the jackets and coolers. The last column shows that the amount of heat removed by the jackets is about in proportion to the cylinder areas. The difference between the temperature of discharge and the temperature at the entrance to the next cylinder indicates the amount of heat removed by the intercoolers. The low temperature of the suction of the intermediate and high pressure cylinders shows that the intercoolers were very efficient.

It will be seen that many of the features in this compressor are such as would be adopted in any large and economical plant for furnishing air at a high pressure. This is more particularly the case with the air end. In the design of steam end, however, the usual

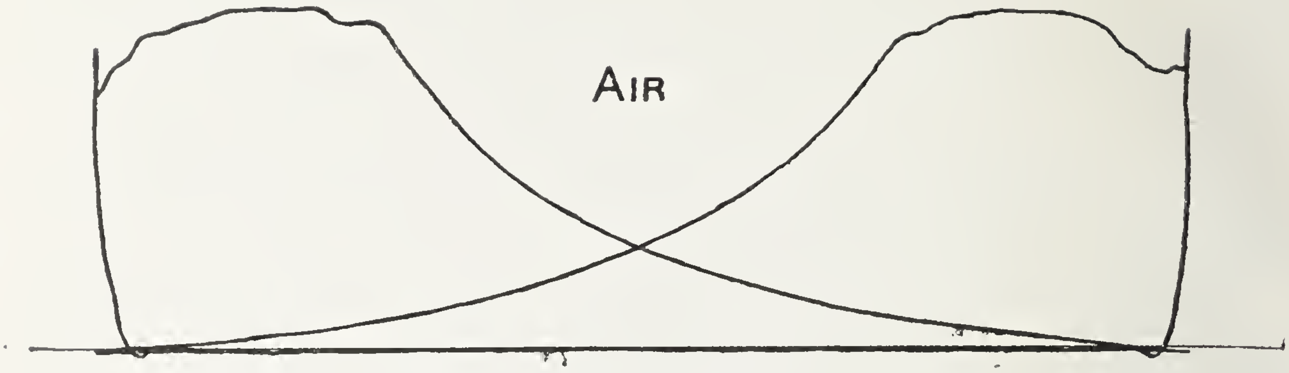


FIG. 33

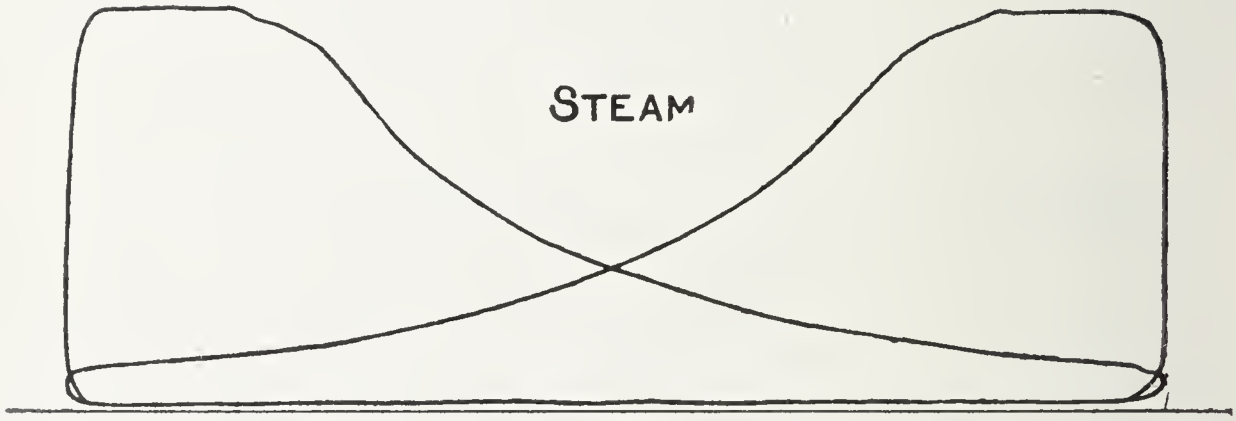


FIG. 34

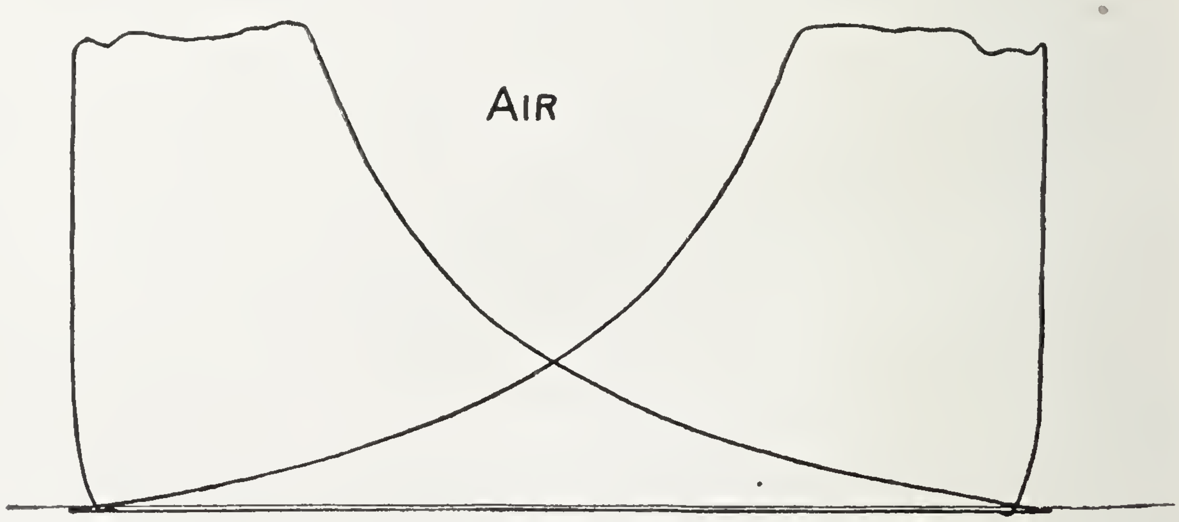


FIG. 35

construction would be compound condensing engines with Corliss valves. In this case though, solidity, simplicity and durability were the principal things desired, while economy of steam was made a minor consideration. Another important point to be considered was that the compressor should have a large capacity in a short time, that is, it should be able to run at a high speed without injury. How well this has been attained is shown by the fact that during part of the test the compressor was run at a piston speed of 568 feet per minute, without vibration or undue heating.

VALVES.

No paper on air compressors would be complete which did not devote some space to a consideration of their most important details—the valves.

With regard to the valves of the steam ends, it will only be necessary to point out the essential differences between the conditions in an air compressor and in an engine for ordinary purposes, such as driving mill machinery or dynamos. In driving dynamos, for instance, the speed must be constant, whatever the load, and the question of economy turns largely on the method of governing. The advantage of governing the cut-off over governing by throttling accounts for much of the superiority of Corliss valves and automatic expansion gear. In an air compressor, however, there is a definite amount of air compressed per stroke, and hence the speed of the compressor should vary according to the demand for air. A compressor is largely self-governing. When the demand is light the pressure in the receiver rises, the work of compression becomes greater, and the engine begins to run more slowly. When the demand is heavy the pressure falls and the machine speeds up again. The only governor that is absolutely necessary is one which will act when the speed rises to the highest safe limit, to prevent the machine from "running away." This might take place when the demand was very heavy or when a break occurred in the discharge pipe.

The most common steam valve for a compressor of medium size is a slide-valve with Meyer cut-off, regulated by hand. A valve of this kind is shown on the H.P. cylinder of Fig. 20. Fig. 34 shows the steam cards from a straight-line compressor with Meyer cut-off. The steam cylinder was 20 x 24, and the air cylinder 22 x 24. The figures for the cards shown are: cut-off, $\frac{1}{4}$; steam pressure, 90; air pressure, 70; revolutions per minute, 50; mean effective pressure (average of two), 43.7.

Another difference between an ordinary engine and the engine of an air compressor is shown by these cards. It will be seen that the amount of compression is very small. One of the principal effects of compression in a steam cylinder is to cushion the reciprocating parts. In an air compressor in which steam and air pistons are on the same piston rod, the cushioning is done very effectually by the compressed air in the air cylinder, hence there is not the same necessity for cushioning by steam.

The most common form of air valve is the poppet valve. Both suction and discharge valves of the high-pressure air cylinder in Fig. 20 are of this type. The discharge valves in Fig. 32 are also poppet valves.

The advantages of poppet valves are that they are very simple, have little tendency to leak, and are easily reground by hand if a slight leak should occur. They are entirely automatic, opening when the pressure on the face exceeds that on the back. This automatic action is particularly desirable for discharge valves, as the pressure of the discharge is variable, and hence a fixed point of opening would not be suitable.

Some objections to poppet valves are as follows: To insure prompt closing at all speeds, the springs must exert considerable force. In the case of inlet valves the throttling caused by the pressure of the springs, while hardly noticeable on the indicator-card, may cause quite a loss of capacity and a small loss of power. A throttling of eight ounces per square inch could hardly be seen on a card taken with a sixty spring, but yet it would cause a loss of 3.4% in capacity, and, at a discharge pressure of 100 pounds per square inch, a loss of about 1.2% in power. Another objection is that a large number of valves are necessary, on account of the small lift that can be allowed each one. A compressor of medium size would have from three to five inlet valves and two discharge valves for each end of each cylinder, making from ten to fourteen valves for each cylinder. The air, being forced to flow in thin streams over the metal, has a chance to become heated during admission, with consequent loss of power. Poppet valves nearly always chatter to some extent, and are liable to break and get into the cylinder, wrecking the machine. The defects of poppet valves are the most serious in the case of inlet valves, so that many makers who retain the poppet discharge valves have substituted some other form of inlet valve.

Corliss valves are used on the air cylinders of a number of com-

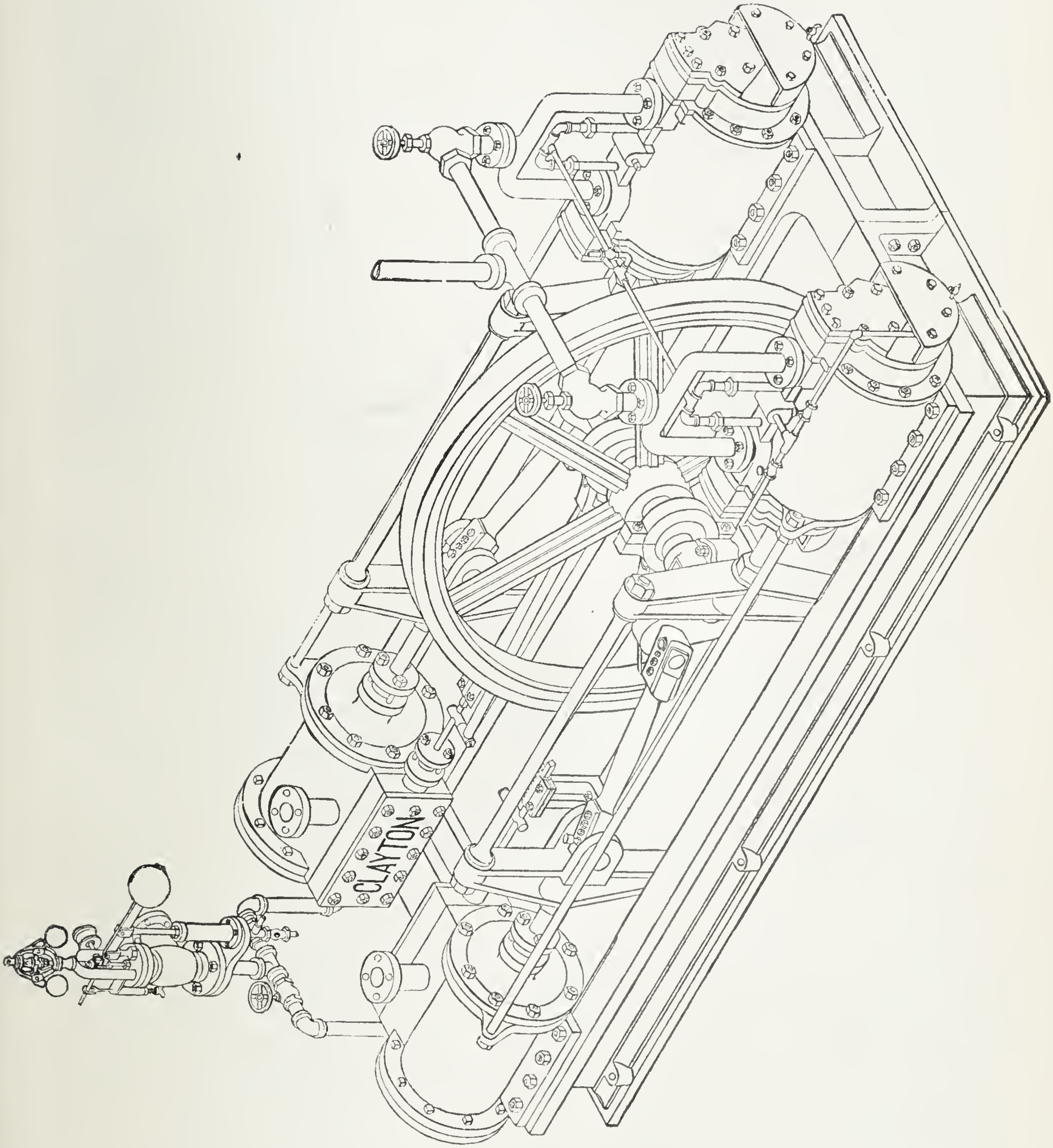


FIG. 36.

pressors. These can easily be used as inlet valves, because the proper point of opening and closing is fixed or very nearly so. But in the case of discharge valves some provision must be made to allow the valve to open at the time when the pressure in the cylinder is equal to the pressure on the other side of the valve. In the Norwalk Compressor shown in Fig. 20, Corliss valves are used on the L.P. cylinder. The pressure of the discharge from the L.P. cylinder of a compound compressor is fixed, so that in this case no special provision is necessary.

Fig. 31 shows two views of the cylinder of a blowing engine designed for a pressure of four pounds per square inch. It is built by the Philadelphia Engineering Works. The discharge valve is double ported to give a large opening with a small valve movement. As the double port increases the clearance it is not used for high pressures. The inlet valve of this cylinder is operated directly by a rod attached to the wrist plate. The discharge valve is closed positively, but is opened by air pressure, by means of an auxiliary cylinder and piston. These can be seen just above the upper valve-arm, in the end view, Fig. 31.

Some of the advantages of Corliss valves are the large opening, which permits the cylinder to be filled with cool air at nearly atmospheric pressure, and the positive movement, which enables the compressor to be run at a high speed. Their disadvantages lie in their well-known tendency to wear and become leaky, in the difficulty of repair, in the large clearance, and in the weakening of the cylinder heads by the long ports. The wear of the valve may be partially obviated by using it for low pressures only and by having the movement take place only when the pressure is nearly balanced on the two sides. In the Nowalk compressor (Fig. 20) the Corliss valves are used on the low-pressure cylinder only. In addition to this, the discharge valves have a pair of cams interposed between the eccentric rod and the valve-arm, so arranged that the valve stands still until the pressure is nearly balanced. In the compressors of the Philadelphia Engineering Works (Fig. 31) the discharge valve opens automatically when the pressure is balanced, and closes before much pressure comes on it.

Fig. 32 shows the air cylinder of the Ingersoll-Sergeant compressors. G G are the inlet valves, placed in the piston. They are without springs or mechanism of any kind, but are opened and closed by the motion of the piston. Their advantages consist in a large opening with very small throw, very slight throttling of inlet air, simplicity and durability, small clearance, and the saving of space in the cylinder head for water-jacketing. Some of their disadvantages are: The closing effort begins at mid-stroke, and increases as the square of the velocity. The air is admitted through a thin hot tube and a hot piston. A considerable leak might occur without its being detected, as it could not very well be heard. The valves are not easily accessible for inspection and repair.

Some peculiar air valves are shown in Fig. 26, which is a section of the air chamber of one end of the compressor whose air cylinder is shown in Fig. 25. The valves are simply rubber rings of circular section, lying in grooves and covering slits in the metal. The pressure of the air expands the rings and uncovers the slits. It will be seen that there are three inlet and one discharge valve. As this is a "wet" compressor the valves are not subjected to a very high temperature, which would soon destroy the rubber.

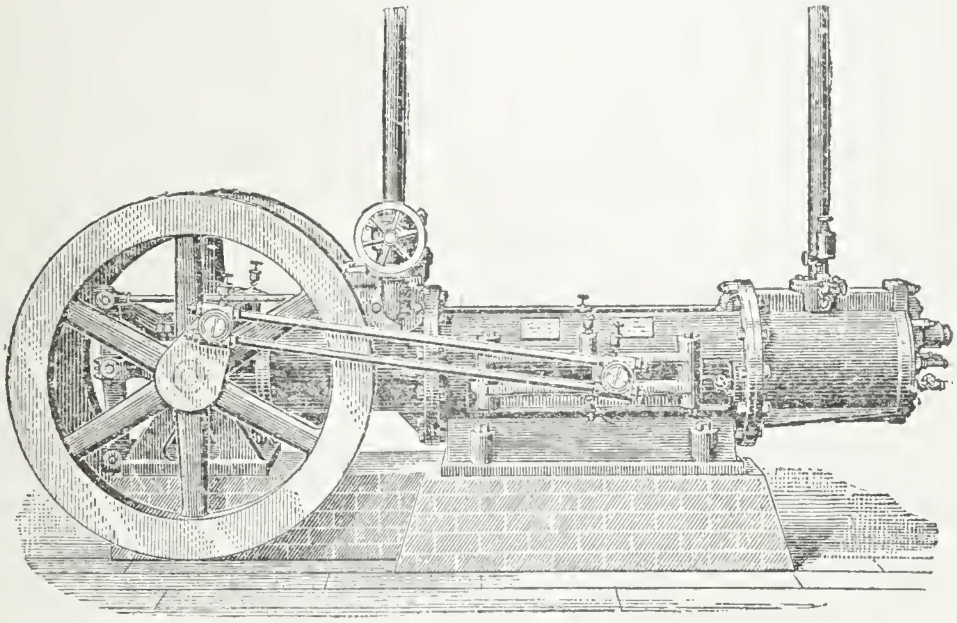


FIG. 37.

The last type of valve which we shall consider is the mechanically controlled poppet valve. This is the type of valve used on the Riedler compressor, where it has given such excellent results.

Fig. 35 shows an air card taken from a compressor with Riedler valves. The air cylinder was 27 x 42, the speed 61 revolutions per minute, and the air pressure 78 pounds gauge. The mean effective pressure is 33.3 pounds per square inch.

The general principle of mechanically controlled poppet valves is to provide a means for taking the pressure of the spring or valve rod off the valve, just before the pressure is balanced on both sides, in order to leave the valve free to open to its full extent when the air pressure on its face exceeds the air pressure on the back. At the proper time the valve is closed, either directly or by allowing a spring to press against it. The movement to operate the gear may be taken from a special eccentric or from the eccentric which operates the steam valve, either directly or through a wrist plate. A part of the mechanism for operating the valves can be seen in Fig. 27, at the end of the large cylinder on the right. This movement is operated from a special eccentric on the crank-shaft.

Objections urged against this type of valve are their complication and the necessarily slow closing, which must be either too early or too late.

With regard to the first, it may be said that the extra complication of the gear is counterbalanced by the fewer number of valves necessary, on account of the high lift which may be allowed. Both suction and discharge valves should close at a definite point, when the crank passes the dead centre, so that it should be possible to make the valve close at that exact point. It will also be evident that, as the piston velocity decreases up to the end of the stroke, the valve might begin to close quite early, without increasing the throttling or the velocity of the air through the valve. It will be seen that mechanically controlled poppet valves possess many of the advantages of ordinary poppet valves and but few of their disadvantages.

The writer wishes to thank the following firms for their kind assistance:

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The Norwalk Iron Works Co., for a blue-print and an electrotype.

The Clayton Air Compressor Works, for an electrotype.

Fraser & Chalmers, Chicago, for blue-prints and air cards.

MUNICIPAL ENGINEERING IN ONTARIO.

By Herbert J. Bowman, O.L.S., M. Can. Soc. C.E.

In the Ontario " Municipal Act " it is provided that

" The Council of every county, township, city, town, and incor-
" porated village may pass by-laws for appointing such Pound-
" keepers, Fence Viewers, Overseer of Highways, Road Surveyors,
" Road Commissioners, Valuators, Game Inspectors, and *other officers*
" as are necessary in the affairs of the corporation, or for carrying
" into effect the provisions of any Act of the Legislature or by-law of
" the Corporation, or for the removal of such officers ; but nothing in
" this Act shall prevent any member of a corporation from acting as
" commissioner, superintendent or overseer, over any road or work
" undertaken and carried on, in part or in whole, at the expense of
" the corporation ; and it shall be lawful for the municipality to pay
" such member of the corporation acting as such commissioner,
" superintendent or overseer."

The foregoing extract may suggest that in the past municipal engineers have not been of such frequent occurrence or importance as pound-keepers, etc., having been classed with the nameless " other officers " of corporations. In a great many of the smaller towns, although expending considerable sums on waterworks, drainage, road improvements, etc., no engineer is employed. A committee of the municipal council is given complete charge of certain work and proceed to carry their ideas into effect, or the whole matter may be left in the hands of the chairman, the other members of the committee being too busy or lacking in interest. If the chairman does not take personal charge of the work, he secures some other " practical " man to act as commissioner, superintendent or overseer, usually some ambitious carpenter or other mechanic, the proud possessor of a spirit level and a two-foot rule, and the work is proceeded with.

If, however, the work in hand is to be let by contract and the " practical " man does not feel equal to the emergency of preparing specifications, an advertisement is prepared after the manner of the following printed in a late paper :

The Town of ——— contemplate building, during the coming summer, Granolithic Sidewalks of four (4) feet and upwards in width, and will be pleased to receive suggestions and figures as to style of construction (specifications) and cost of same, from parties in that line of business.

Cheap and durable walks are what are wanted.

It is not necessary to point out the defects in such a method of carrying on public works, except to say that the chances are that the honest contractors will be beaten and good work will not be secured. Undertakings of greater importance, such as water-works and sewerage, are often advertised as open for tenders, each contractor to furnish his own plans and specifications, and the contract is awarded by a council composed, perhaps, of good business men, but men who know very little about the engineering questions involved.

The favored contractor is profuse in his thanks to the Council for recognizing the advantages (?) of his tender, and takes the first opportunity of confidentially informing this body that it is entirely unnecessary to go to the expense of employing an engineer to see that the specifications are carried out. In other cases, after the contract is signed and an engineer appointed, it is found that the specifications are vague and full of loop holes, so that a large bill of extras is piled up and the contract settled by an expensive law-suit. The fact is that, except perhaps in a few of the larger cities, there is room for much improvement in the matter of designing and constructing public works in the different municipalities in the province.

The remedy for this state of affairs, the writer is convinced, does not lie in the way of legislation, as in this democratic country no coercive measures can be adopted even if the end is for the common good. Public opinion will have to be educated up to put more reliance in permanent and responsible officers to take charge of the spending of public moneys. In this the rural municipalities are leading the way, for, through the working of the "Ditches and Watercourses Act" and the "Drainage Act," the township engineer has become a very useful officer, and in the matter of drainage is the recognized authority. Many of these men are engineers of experience and practically all are Ontario Land Surveyors, possessing the qualifications necessary for this work. However, when we come to look into the question of engineering for the larger villages and towns, we find that little attention has been paid by engineers in this country to this class of work. The bulk of the students in the engineering colleges aspire to be Electrical or Mechanical Engineers, and the few who take up Civil Engineering are looking forward to railway or government work, in spite of the fact that all these are much overcrowded. In municipal engineering there are still openings, but the young engineer should be qualified in practice as well as theory, in short, must be a "practical" man, and not afraid to commence like any young lawyer or doctor in some out of the way place, and grow up with the country. For a while, no doubt, he may have a struggle to make both ends meet, and may have to take up some other work not exactly of an engineering character, but which will add to his knowledge of business and municipal affairs. For instance, a case has come to the writer's notice where a young engineer performed the duties of assessor where he was located in the early days of his career, and has since risen to the top of the ladder, being chief engineer of one of the greatest railway systems on this continent. The young municipal engineer, to succeed, must also be an Ontario Land Surveyor, and thus be in a position to locate all the disputed property lines in his neighborhood, as well as prepare plans for registration of new surveys and new roads, etc. During the year's apprenticeship to some practising surveyor, the college graduate will also add to the practical knowledge that he is assumed to have acquired in the vacations during the college course.

At present there is no organization in Ontario to bring municipal engineers together to read papers and discuss topics of mutual interest. The National Engineering Society, with headquarters at Montreal, does not fill this need and should not be expected to. A provincial organization seems to be necessary, such as the State Engineering Societies of Michigan, Illinois, Ohio, Indiana, Iowa, and other local engineering clubs. This society should have permanent headquarters in the provincial capital. It may be said that the Ontario Land Surveyors' Association already fills this need, and to a certain degree that is true, but many members of that association who are also engineers, have so far silently endeavored to keep purely engineering questions in the background. Now that the attempt to form a close corporation of engineers in Ontario seems to have been abandoned, we may expect more attention to be paid to the consideration of the advisability of enlarging the scope of the Ontario Land Surveyors' Association so as to include Municipal Engineering, and thus aid in securing to municipalities competent men to design and construct their different public works.

CRUSHING STRENGTH OF WHITE PINE.

By A. H. Harkness, Grad. S.P.S.

The tests, the results of which are given in the following tables, though not extensive enough to permit of any very definite conclusions being drawn, may prove of interest as serving to show the relative crushing strength of pine transversely and longitudinally placed, that is, with the load applied to the sides of the fibres, and with the load applied to the ends; also the effects of moisture on the longitudinal crushing strength.

The specimens used in the tests were cut from pieces of white pine about three and three-quarter inches square, and are from the heart wood of small trees. Although they were not all cut from the one piece, the material in them was so similar in quality that the different tests will admit of comparison.

The pieces from which the specimens were taken were purchased from a city lumber firm 21st October, 1896, and represent fairly the average quality of pine from which 4 x 4 inch scantling is cut. They were stored in the laboratory of the School of Practical Science until the tests were made.

The first table gives the transverse crushing strength tested on March 17th, 1897. The specimens were all cut in four-inch lengths from one piece, the specific gravity of which was 37.25, and which contained 12.2 per cent. of moisture calculated on the weight after being dried. This is about the normal amount of water contained in thoroughly seasoned wood protected from the weather. The loads required to produce a compression of three per cent. and of fifteen per cent. respectively, are given in table No. 1 in the fourth and fifth columns. The second column gives the thickness of the block, and the third the dimensions of the area subjected to pressure. Figs. (a), (b) and (c) show the different ways in which the blocks were placed in the machine in regard to the position of the heart of the wood and the annual rings. The letters in the sixth column refer to these figures.

The maximum strength of the wood is sometimes reached before the block is compressed fifteen per cent. In fact the load begins to increase very slowly shortly after the three per cent. limit is reached, at perhaps about five per cent. compression. When the pieces are placed as in Fig. (a) the maximum load is always reached at a compression of less than fifteen per cent., the annual rings seeming to act somewhat like curved plates, the rings splitting apart and the side toward which they are convex bulging out, as shown in Fig. (d). When the blocks are placed as in Fig. (b) the rings simply become pressed closer together, and the load will continue to increase indefinitely. Failure is accompanied by splitting above the heart, which seems to act as a wedge, as shown in Fig. (d). When the heart is near the centre failure is accompanied by both splitting above and below the heart, and bulging out at the sides as in Fig. (f).

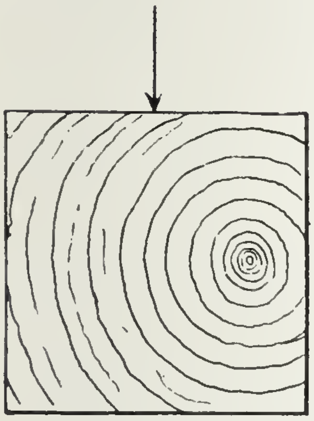

Fig a

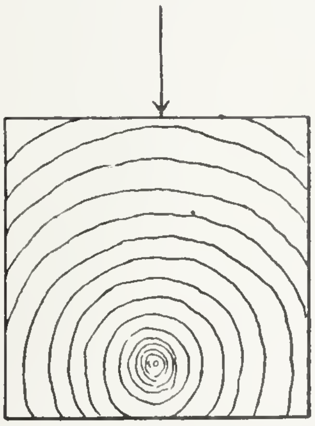

Fig. b

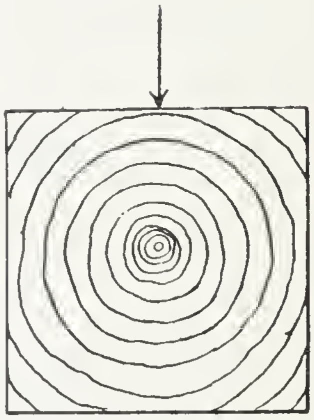

Fig. c.

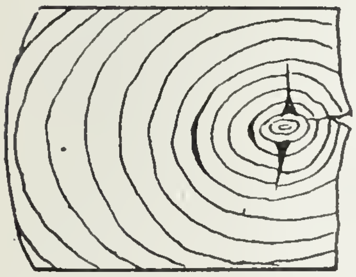

Fig. d

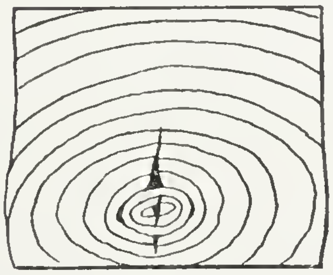

Fig. e

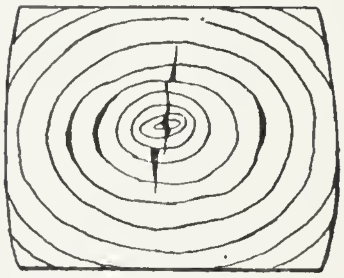

Fig. f

Table No. 2 shows the longitudinal crushing strength. The specimens were cut in eight inch lengths with the exception of the five marked with asterisks, which were each four inches long.

Those of which the crushing strengths are given in column A, were cut from the same stick as the four-inch pieces tested transversely, and were tested at the same time, March 17th, 1897. Those given in columns B, C and D were tested on December 21st, 1896, and were cut from the ends of three different sticks, which had been tested as long posts on December 16th, on which date the specific gravities and percentages of moisture were as given in the following table. As the pieces would have lost some moisture in the five intervening days, the values given for B, C and D are higher than the actual.

	A	B	C	D
Specific gravities	37.25	51	46	53
Percentage of moisture.	12. 2	23		22.5

The percentage of moisture in C was not determined, but was probably about the same as in B and D.

A comparison of the results given in table No. 1 with those in column A, table No. 2, both sets of tests being made on specimens from the same piece of timber, shows that for well seasoned pine the longitudinal crushing strength is about ten times as great as the transverse strength to resist a compression of three per cent. Hence it is quite evident that in the case of a wooden column in order to develop its total crushing strength, it is necessary to have a capital to receive any wooden beams resting on it. The area of the top of the capital should be about ten times the area of the column, or the top of the capital should be over three times the diameter of the column on which it rests. The same thing applies to the cases of columns supported by timber placed horizontally. Of course in the case of long posts in which the full crushing strength of the cross section is not reached, the ratio between the area of the capital and the column need not be so great.

A comparison of column A in table No. 2 with the columns B, C and D, shows the very decided effect which the quantity of moisture in timber has on its crushing strength.

TABLE NO. 1.

No. of Test.	Thickness in inches.	Breadth in in. by Length in in.	Load at 3% Compression in lbs. per sq. in.	Load at 15% Compression in lbs. per sq. in.	Manner of placing block.	Remarks.
1	3.73	3.75 x 3.97	435	524	A	
2	3.73	3.75 x 4.00	475	478	A	
3	3.73	3.75 x 4.00	556	579	A	
4	3.72	3.73 x 4.00	468	576	B	
5	3.73	3.70 x 4.00	537	645	C	
6	3.73	3.73 x 4.00	483	576	C	
7	3.74	3.74 x 3.98	455	551	A	Knotty and splintery.
8	3.73	3.73 x 3.98	499	613	C	
9	3.73	3.74 x 4.00	408	482	C	A pitch ring about heart.
10	3.72	3.72 x 4.02	516	618	C	
11	3.72	3.73 x 4.02	493	593	C	Large season crack.
12	3.73	3.75 x 4.03	458	510	C	Knotty and pitchy.
13	3.74	3.71 x 4.02	505	584	C	
14	3.73	3.74 x 4.00	406	475	B	Pitch ring.
15	3.75	3.75 x 4.05	486	486	A	Knot at each end.
16	3.74	3.77 x 4.02	538	638	C	Season cracks.
17	3.73	3.70 x 3.96	420	542	C	
18	3.73	3.72 x 4.00	435	555	A	
19	3.72	3.73 x 4.06	542	621	C	
20	3.73	3.73 x 4.02	413	413	B	
21	3.73	3.71 x 3.95	534	551	C	Gummy.
22	3.74	3.74 x 4.00	441	541	A	Gummy and shaky.
23	3.73	3.75 x 4.00	437	513	C	Pitch ring.
24	3.72	3.72 x 4.02	543	597	B	An enclosed knot.
25	3.72	3.74 x 4.02	440	563	C	
26	3.74	3.70 x 4.00	550	596	C	
27	3.73	3.70 x 6.00	489	600	C	
		Average	480	560		

TABLE NO. 2.

No.	Crushing strength per square inch.			
	A	*B*	*C*	*D*
1	5,110	3,641	3,598	3,513
2	4,746	3,982	3,562	2,948
3	4,848	4,391	4,078	3,043
4	5,317	4,096*	3,740*	3,332
5	4,934	3,883*	3,826*	3,947
6	5,050	4,426*		3,115
Average	5,001	4,069	3,761	3,316

TESTS ON THE TENSILE STRENGTH OF STEEL BOILER PLATES.

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The following table gives the results of tests of specimens cut from two plates of flange steel. Six specimens, marked A and B respectively, were cut from each plate, those with odd numbers lengthwise, or in the direction of rolling, and those with even numbers crosswise, or parallel to the rolls. The specimens were sheared from the plates and then planed to an uniform width of 2 inches, the metal injured by shearing being removed.

The tests were made on the 200,000 lbs. Riehlé Testing Machine in the Laboratory of the School of Practical Science, the specimens being placed in the machine with a clear length of 15 inches between the jaws.

The Yield Point was determined by the drop of the beam, and was strongly marked, every specimen stretching considerably without any further increase in load.

An examination of the table will show that both plates were slightly stronger crosswise than lengthwise, but no general conclusions can be drawn from such a small number of tests.

Tests which were made at the Watertown Arsenal in 1885 on 48 steel plates, varying in thickness from $\frac{3}{16}$ inch to $\frac{3}{4}$ inch, one specimen cut lengthwise and one crosswise from each plate, indicated that the strength in each direction was substantially the same; in many of the plates it was almost exactly the same, in about half the others the strength lengthwise was a little greater, and in about half a little less than the strength crosswise. These conclusions have been confirmed by other tests.

The percentages of elongation in column 7 were calculated from the formula of the Committee of the American Society of Civil

Engineers,[*] who recommend that the percentage of elongation in 8 inches should be specified as a function of the ultimate strength of the test specimen, by the formula

$$\text{Per cent of elongation in 8 inches} = \frac{1{,}500{,}000}{\text{Ultimate strength}}.$$

Those in column 8 were calculated by Prof. Johnson's modification of the above formula.

$$\text{Per cent. of elongation in 8 inches} = \frac{1{,}800{,}000}{f - 10{,}000} - 10$$

Where f is the ultimate strength of the test specimen.[†]

These formulæ express Tetmajer's criterion, which is essentially, that if two steels whose ultimate strengths may vary within assigned limits are to be equally suitable for the purpose of construction, the coefficients of ultimate resilience shall lie within narrow limits.

If instead of the ultimate strength we take the elastic limit Tetmajer's criterion would require that the coefficient of elastic resilience shall be constant.

Let λ = the elongation in length l.

$p.$ = stress per sq. inch at elastic limit.

$s.$ = strain = $\frac{\lambda}{l}$

A = Area of cross-section.

E = Young's modulus.

K = coefficient of elastic resilience.

The resilience or the work done by the gradually applied stress $= \int p\,\mathrm{A}\,d\lambda = \mathrm{A}l \int p.ds.$

By Hooke's law $p = \mathrm{E}s$.

Hence the resilience $= \mathrm{A}l \times \frac{1}{2}\mathrm{E}s^2 = \frac{1}{2}ps \times \mathrm{A}l.$

The coefficient of elastic resilience K or the work done per unit of volume $= \frac{1}{2}ps$, and depends only on the material.

If l = 8 inches the percentage of elongation in 8 inches = $\frac{100\lambda}{l} = 100s$ and $\mathrm{K} = \frac{1}{200}p \times$ per cent. of elongation in 8 inches.

This would apply to the ultimate strength and elongation, and ultimate resilience if Hooke's law were true, and if the material continued to be homogeneous up to the breaking point. But in structural steel neither of these conditions hold.

Beyond the elastic limit there is no known relation between p and s by means of which the expression for the resilience may be integrated, and the determination of the coefficient of ultimate resilience must rest on direct observation of the material under test.

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[*] *Engineering News*, July 16th, 1896.

[†] Digest of Physical Tests, Oct., 1896.

The Committee of the American Society of Civil Engineers also recommend that the specified per cent. of contraction in area shall be $\frac{2,800,000}{\text{Ultimate strength}}$.

The values specified by this formula have been calculated, and are given in column 9 for the purpose of comparison with the observed percentages of contraction in area.

	MARK.	Cross-section in inches.	Yield Point in pds. per sq. in.	Ultimate Strength in pds. per sq. in.	Per cent. of Elongation in 8 ins.	Per cent. of contraction in area.	$\frac{1,500,000}{f}$	$\frac{1,800,000}{f-10,000}-10$	$\frac{2,800,000}{}$
Lengthwise.	1 A......	2x·372	38,770	51,100	32·	59·5	29·3	33·9	55·
	3 A......	2x·373	38,200	51,100	36·3	64·5	29·3	33·9	55·
	5 A......	2x·373	39,400	53,550	30·5	55·3	28·	31·4	52·3
	Average.	....	38,800	51,900	32·9	59·7	29·	33·1	54·
Crosswise.	2 A......	2x·382	41,230	58,180	25·5	50·2	25·8	27·5	48·2
	4 A......	2x·385	38,180	55,400	27·5	56·8	27·2	29·8	50·5
	6 A......	2x·384	38,400	55,730	30·	51·3	27·	29·3	50·4
	Average.	....	39,270	56,430	27·7	52.7	26·6	28·8	49·6
Lengthwise.	1 B......	2x·362	41,000	51,800	28·1	54·0	29·	33·	54·2
	3 B......	2x·365	40,550	51,900	28·1	53·5	29·	33·	54·
	5 B......	2x·369	40,900	52,600	30·5	58·0	28·6	32·3	53·3
	Average.	....	40,800	52,100	28·9	55·2	28·8	32·8	53·8
Crosswise.	2 B......	2x·384	39,850	53,100	28·1	57·0	28·3	31·8	52·8
	4 B......	2x·384	38,600	52,400	30·	57·5	28·7	32·5	53·4
	6 B......	2x·383	38,800	52,900	28·8	57·5	28·5	32·0	53·
	Average.	....	39,100	52,800	29·6	57·3	28·5	32·1	53·1